Chapter 10
The Traveler

Part I of this book relies on reports by others of Cavendish's behaviors. There is no reason to doubt the reports and the conclusions drawn from them, but by themselves they are missing what only Cavendish can tell us. His scientific papers do that, but they reveal only part of his world, and his personality is largely concealed. A partial exception is journals he and Blagden kept of travels in the 1780s. Because his travels exposed him to a common world, what he selected from it is revealing of his personality.

"The eye sees what it brings the power to see." This passage is by Thomas Carlyle, quoted in *The Five Senses; or, Gateways to Knowledge*, an elementary account of the main human senses, the "living inlets of learning." The author is George Wilson, Cavendish's biographer, who understands Carlyle to mean that the eye is educated to see what interests its owner. He gives examples: "The sailor on the lookout can see a ship where the landsman sees nothing; the Esquimaux can distinguish a white fox amidst the white snow.… The astronomer can see a star in the sky, where to others the blue expanse is unbroken; the shepherd can distinguish the face of every sheep in his flock; the mosaic worker can detect distinctions of color, where others see none."[1] What the natural philosopher Cavendish's educated eye saw on his journeys, he and Blagden recorded in their journals. In this chapter, we look at what it was.

We should be aware of an ill-defined category of persons known as "eccentric travelers." According to an author of a collection of biographies of such persons, eccentrics and travelers are often one and the same because they want the same thing, to escape from conventions of society. Eccentric travelers commonly approach new scenes with a more open mind than do typical travelers. They tend to be directed and well informed, illustrating a central fact about eccentric behavior, that it "is not the result of ignoring logic but of pursuing it to unusual extremes."[2] Following are several examples of well-known eccentric travelers. Charles Waterton, the English naturalist we met before, wrote a book about his travels, *Waterton's Wanderings in*

[1] Wilson, *The Five Senses*, 6, 32–33.

[2] John Keay, *Eccentric Travellers* (London: John Murray, 1982), 13–15.

R. McCormmach, *The Personality of Henry Cavendish - A Great Scientist with Extraordinary Peculiarities*, Archimedes 36, DOI 10.1007/978-3-319-02438-7_10,

South America, which inspired the schoolboys Charles Darwin and Alfred Russell Wallace. An enemy of pollution and early friend of the environment, he built a 9 ft wall 3 miles in length around his estate, enclosing a nature reserve. There are many stories of his odd behavior. On a visit to Italy, he showed his "increasing eccentricity" by balancing on one leg on the head of the Guardian angel mounted on top of the castle Saint Angelo. He was said to disappear under the dinner table and bite the legs of guests, imitating a dog, and he invented a new method of preserving animal skins, with which he made caricatures of his enemies.[3] Edward Wortley Montagu, 1713–76, was an English author who traveled widely in the West Indies and the Middle East. His mother Lady Mary, herself an eccentric, described him as "an excellent linguist, a thorough liar, and so weak-minded as to be capable of turning 'monk one day, and a Turk 3 days after.'" She knew her son. In Constantinople, Montagu dressed like a wealthy Turk, sporting buttons and buckles worth £2,500, wearing a beard and turban, adopting Turkish manners, and professing to be a Muslim. This "spectacular 'going native' was the culmination of a career of conspicuous social nonconformity." He presented a narrative of his travels to the Royal Society, of which he was a member. His scholarship is minor, "but he claims a place in any gallery of notable eccentrics."[4] Thomas Manning, 1772–1840, devoted himself to the study of China. Determined to penetrate to the center of the Celestial Empire, he succeeded after many adventures in glimpsing Peking, and he was the first Englishman to visit Lhasa in Tibet and to interview the Dalai Lama. Although he published nothing, he is credited with being the first lay scholar of China in Europe. Upon returning from his travels in Asia, he retired to a house he never furnished, filling it instead with his library of Chinese books, said to be the largest in Europe. Taking "delight in the most monstrous paradoxes," a fellow interpreter said, he "did everything in his own odd and eccentric way," giving as an example Manning howling like a dog and cursing in Chinese to get attention; the Chinese thinking him mad took him across the river, which action was all he wanted.[5] What these travelers had in common was a practice of carrying their eccentricities to "unusual extremes." Cavendish, as we will see, was like them an "eccentric traveler," though his eccentricity was less extreme than theirs, and less amusing.

10.1 Travel Writings in the Eighteenth Century

Lawrence Sterne, novelist and traveler, wrote, "The love of variety, or curiosity of seeing new things, which is the same, or at least a sister passion to it, – seems woven into the frame of every son and daughter of Adam." A scholar comments on Sterne's

[3] Foote, "Waterton," 574. Anon., "Charles Waterton," http://en.wikipedia.org/wiki/Charles_Waterton.

[4] Isobel Grundy, "Motagu, Edward Wortley (1713–1776)," *DNB* 38: 714–16, on 716. Anon., "Edward Wortley Montagu," http://en.wikipedia.org/wiki/Edward_Wortley_Montagu.

[5] Keay, *EccentricTravellers*, 70. Elizabeth Baigent, "Manning, Thomas (1772–1840)," *DNB* 36: 509–10, on 510. Anon., "Thomas Manning," http://en.wikipedia.org/wiki/Thomas_Manning_(sinologist).

quotation: "A person who travels subjects the structures of his personality, his mind and his emotions to a new process of experience, which may, in extreme cases, destabilize the traveller's previous world-view."[6] Cavendish was Sterne's curious traveler, who subjected his mind and emotions to new experiences, but as we should expect, he emerged with his worldview intact and confirmed.

Cavendish's main destinations were sites of British industry at the beginning of what we know as the Industrial Revolution. He and Blagden inspected mines, furnaces, and machinery, and they recorded what they saw in their journals. By this time, the keeping of journals was commonplace. Before we begin the account of Cavendish's travels, we take up the subject of writing about travels.

Travel writing can never be completely objective, for writers bring with them preconceptions and anticipations, but if the object of their travels is scientific, the subjective element is minimized.[7] Cavendish's and Blagden's travel writing is scientific. The entries in their journals are informative, the writers nearly invisible. We might compare them to laboratory notes, the laboratory happening to be movable. As such, we might wonder if it is meaningful to talk about their journals as travel writing.

It is expected of travel writing that it narrates a journey. Even where the writing is severely factual, there should be a narrative flow,[8] and there is little sense of it in Cavendish's and Blagden's journals. They describe what drew their eye at one location, for example, forges, then they do the same at the next location; they say nothing about the journey between stops, or at most mention points of geological interest observed in passing. On this count too, the journals would seem barely to qualify as travel writing.

Yet they do qualify. Like most travel books, their journals had a theme, certain things Cavendish wanted to see or do, which his traveling companion Blagden conveyed to persons he contacted before they set off. To carry it through, Cavendish had a travel plan; his journeys were not a disorderly wandering. To journal entries, he and Blagden assigned dates and locations, and at every location they saw what they came to see, things relating to the theme. Because the journals were not intended to be published, they needed to satisfy no one but their authors. The narrative character of the journals was left largely implicit, but it was there. The departures of the journals from other travel writing lie in emphasis not in nature.

Improvements in roads and carriages encouraged travel in the eighteenth century and with it a curiosity about the world. There was a corresponding market for first-hand accounts of travels. Travel writers took readers to unfamiliar sights, and provided practical information for readers planning to travel themselves, recommending places to see and where to stay.[9] The time had passed when travelers' accounts

[6] Barbara Korte, *English Travel Writing from Pilgrimages to Postcolonial Explorations*, trans. K. Matthias (New York: St. Martin's Press, 2000), 44.

[7] Ibid., 6.

[8] Ibid., 9.

[9] Charles L. Batten, Jr., *Pleasurable Instruction: Form and Convention in Eighteenth-Century Travel Literature* (Berkeley, Los Angeles, London: University of California Press, 1978), 3.

freely mixed fact and fiction and spread extraordinary fables. Tastes had changed, people had come to demand believable accounts of the world, and travel writers were expected to report faithfully what they had seen. "Truth and sound knowledge" were the proper subject of travel writers, the travel writer and merchant Nathaniel Wraxall wrote in 1775. "In the travels of a Philosopher," the *Monthly Review* said, we have "the discoveries of science, the improvements of art, the extension of knowledge." Major travel books reported journeys undertaken in the spirit of the Royal Society, and the proper form of writing, according to the *Monthly Review*, paid homage to the ideal of the Royal Society, "a plain unornamented style." The English editor of a Swedish travel book wrote that "every authentic and well-written book of voyages and travels is, in fact, a treatise of experimental philosophy." The traveler was foremost a researcher.[10] Natural philosophers, as we would expect, appeared among the new groups of enthusiastic travelers. In the year Cavendish made his first journey, 1785, the London chemist William Higgins made a journey to visit British factories, following an earlier similar journey by another London chemist William Lewis.[11]

Factualness and plain writing in the spirit of the Royal Society were one ideal of travel writing in the eighteenth century. There were others. Authors often said that they kept a record only for their own use or that of their friends, but this claim could be ingenuous. To appeal to readers and critics, they found they needed to do more than truthfully describe their journeys: they needed to write about them in a pleasing and entertaining way. This need gave rise to a distinctive kind of travel writing, one which blended description with artistic style. Authors of some of the most popular books of travels were literary men such as Sterne, Daniel Defoe, and Samuel Johnson.[12]

Readers of travel books desired novelty above all else. To satisfy the desire, in the last quarter of the eighteenth century, travel writers included new categories of observations such as "men and manners" and "character and manners," which dealt with the habits, laws, religions, and national characters of the inhabitants. Another and more significant trend in travel writing was a change in sensibility: readers' attention was directed to the beauty and grandeur of the landscape, subjective responses and feelings taking precedence over facts. The new writers were known as "picturesque" and "sentimental" travelers.[13]

Let us see what books of travels published around the time of Cavendish's journeys looked like. In 1778–83, Thomas Pennant, a Welsh naturalist and member of the Royal Society, brought out a handsomely illustrated two-volume account of his travels in his own land. In the advertisement of the book he promised readers what the "world justly loves," "reality." He also promised "wild and romantic scenery," but overall his writing is densely factual, with a strong antiquarian emphasis. He closely described the terrain, history, natural history, monuments, tombs, and

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[10] Ibid., 5, 7, 39, 44, 72.

[11] A. E. Musson and E. Robinson, *Science and Technology in the Industrial Revolution* (Toronto: University of Toronto Press, 1969), 122.

[12] Batten, *Pleasurable Instruction*, 3, 45.

[13] Ibid., 75, 79, 91, 96–97, 109.

churches of Wales. He also gave some attention to the mining of coal, iron, lead, zinc, copper, and silver, and to the associated mineral tracks, though little attention to methods and machinery.[14] Another form of travel book was letters written in the course of a journey. An example is the account of a tour of England, Scotland and Wales in 1778 by Richard Joseph Sullivan, a writer born of Irish parents, and a member of the Royal Society. His observations were whimsical, ecstatic about nature, and without discernible order. He toured Chatsworth, the country home of the duke of Devonshire, which disappointed him, finding the house full of old furniture and the grounds filled with dead walls, spouting horse fountains, and other clutter. He hoped that in time the estate would be restored to its former reputation. Industry was not his subject, though in Birmingham he visited Matthew Boulton's manufactory, a familiar tourist stop. To describe its productions, he said, would require "a quicker degree of comprehension" than his; he found the garden there more interesting than the manufactured buttons and buckles. While he was there he was told about the benefits of canals, and these "stupendous works" caught his attention: "the spirit of industry will do any thing," he said. He believed that manufactures like all the other arts of civilization were connected through travel. "Of all the active employments of civil society, that of travelling seems the most important. The mind, restless and eager in its pursuits, pants after novelty,"[15] a justification of most travel books.

We turn to two travel books with a different perspective, combining a serious concern with industry and a feeling for landscape. Edward Daniel Clarke, world traveler, mineralogist, and chemist, toured England, Wales, and Ireland in 1791. The rugged country of North Wales had an "angry grandeur," he said, and he appreciated "wild scenes" and "picturesque landscapes," but he drew the line at the "affected refinement of a modern sentimentalist." He was interested in the national character of the peoples, in their manners, dress, and features, in ruins, churches, and houses, and in "fine prospects." He included incidents and vignettes, both entertaining and informative. In Cornwall, he described in some detail the extraction and smelting of tin ore, and in Wales the mining and smelting of copper. He responded to the human side of mining. Descending to a depth of 80 fathoms in a coal mine, he was impressed by the endurance of the miners and dismayed by the "cutters, as they are called, a troop of poor miserable black devils, working away their very lives amidst sulfur, smoke, and darkness."[16] Arthur Young, a Scottish agricultural improver and writer, toured South Wales and South Midlands in 1776. Drawn to fine prospects and "rural beauties," he gave a poetic description of Drislan Castle and its setting: "Upon the whole I think this spot the most picturesque residence I have seen in England. Hill and dale, and wood and water necessarily unite to form many beautiful scenes: they are the notes which must every where give the harmony of the landscape, but they are here

[14] Thomas Pennant, *A Tour in Wales MDCCLXX*, 2 vols. (London, 1778–83) 1: i, 415–24.

[15] Richard Joseph Sullivan, *Observations Made During a Tour through Parts of England, Scotland, and Wales. In a Series of Letters* (London, 1780), 141–42, 171–72.

[16] Clarke, *Tour Through the South of England, Wales, and Part of Ireland,* 80–89, 198–201, 274, 293–97.

accompanied with their richest melody." He also described in detail, often quantitatively, fields of cabbages and turnips and herds of cows and sheep. He gave the rents of farmland, the price of hay, the yield of wheat, barley, and oats in bushels per acre, the quantity and cost of lime spread over the fields, the number of calves per cow, and the pay of laborers. He described the land and the towns, how the people lived, how they dressed, and what they looked like. Agriculture was his primary interest, but he was interested in industry too. In Birmingham, he came to an edged-tool manufactory, where bloomery cinders, refuse from previous iron-ore smelting, were re-melted and used. "Such is the superior skill of the present age over the preceding, that they get almost as much iron from them, as from fresh ore." Because of recent inventions, buttons were better made, woolen cloth was better woven, canal locks were better constructed. "What trains of thought, what a spirit of exertion, what a mass and power of effort have sprung in every path of life, from the works of such men as Brindley, Watt, Priestley, Harrison, Arkwright…. In what path of life can a man be found that will not animate his pursuit from seeing the steam engine of Watt?" Young was a perceptive traveler, responsive to progress in all its varieties. His travel account was informative, filled with objective observations and sound judgments. It also showed aesthetic appreciation and feeling.[17] To Young, but to other travel writers too, industry with its new technology was inspiring and worth a look.

Cavendish had a choice of ways to keep a journal. Of the writers above, he was closest to Young. Young distinguished two forms of travel reporting: a diary or autobiographical register of the journey, and a summary of results of the journey. He recognized that almost all travel books were of the first kind; they had greater credibility, though at the cost of repetition and digressions. The advantage of travel books of the second kind was brevity and forcefulness. Young combined both kinds in his travel writing, designating the first part as "Journal" and the second part as scientific "General Observations." James Boswell in his book of travels in Corsica in 1768 used the same organization as Young, only reversing the order of the two parts.[18] To some degree, Cavendish followed their plan. For each of his three journeys in 1785–87, he or Blagden or both kept a journal, and later he wrote up the geological results in a separate text, summarizing his observations on strata.[19] Cavendish's interest, however, was narrower and more focused than Young's.

It would appear that his model came from the Royal Society, which in the second half of the eighteenth century directed a number of expeditions to the far corners of the world. In the decade before his own journeys, Cavendish served on a committee

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[17] In 1768, Arthur Young published *A Six Weeks Tour through the Southern Counties of England and Wales.* He also published his account of this and other tours in the periodical he edited, *Annals of Agriculture.* The quotations above are from the latter source, not paginated. Arthur Young, *Tours in England and Wales, Selected from the Annals of Agriculture,* http://www.visionofbritain.org.uk/text/contents_page.jsp?t_id=Young.

[18] Batten, *Pleasurable Instruction*, 32–33.

[19] Henry Cavendish, untitled, 21-page paper on observations of strata, Cavendish Scientific Manuscripts, Devonshire Collections, Chatsworth.

of the Royal Society ordered to draw up scientific directions for a voyage to the North Pole by C. J. Phipps, the principal object of which was to determine how far navigation was possible in the direction of the North Pole. The secondary object was to carry out scientific investigations. Phipps took with him a range of scientific instruments, including a thermometer invented by Charles Cavendish, which was used to take the temperature of the sea down to 780 fathoms. Henry Cavendish gave Phipps an explanation of this thermometer including a correction to be made of the readings based on John Canton's demonstration of the compressibility of water and other liquids, which his father had confirmed for the Royal Society. Phipps's account, *Voyage towards the North Pole,* consists of a narrative of the voyage followed by appendices containing observations and experiments, a variant on Young's plan of a travel journal. The narrative was factual, in keeping with the object of the voyage, but at the same time it recounted an adventure. At one point the ships were hemmed in by ice, and the crew was resigned to abandoning them, but in the end the ships broke free. There were stunning prospects, recorded by an artist of the crew. Great bodies of ice filled valleys between high mountains, breaking off from vertical faces at the sea to form icebergs. "The black mountains, white snow, and beautiful colour [light green] of the ice, make a very romantick and uncommon picture."[20] This was a rare picturesque digression; for the object of Phipps's travel book was not to please but to record scientific results useful to navigation, geography, and natural history.[21]

Toward the end of the century, it became fashionable for the upper classes to travel through England, Wales, and Scotland. The internal tour became a competitor to the Grand Tour on the Continent, the traditional introduction of largely upper class youth to the cultural roots and fashionable society of Europe. By then the Grand Tour had been largely written out anyway. In his account of a tour through Wales, Thomas Pennant said that Britain had as much to offer as the Continent in the way of natural history and art.[22] If he had included industry, he would also have been correct. When Cavendish set out on a journey to the mines and metal works in Wales in 1785, he was in step with the times.

10.2 The Journeys

Like other travel writers, Cavendish and Blagden wrote in the first-person, in their case, "we." They used the personal pronoun sparingly, following the practice of travel writers wishing to avoid the appearance of egotism. The new trends in travel

[20] Constantine John Phipps, *A Voyage towards the North Pole, Undertaken by His Majesty's Command, 1773* (London, 1774), 27, 32–33, 70, 142, 145. Henry Cavendish, "Rules for Therm. for Heat of Sea," Cavendish Scientific Manuscripts, Devonshire Collections, Chatsworth, III(a),7.

[21] Batten, *Pleasurable Instruction*, 28.

[22] Ibid., 92–94.

writing did not appear in their journals. The object of the picturesque or sentimental traveler was to entertain or arouse feeling. The object of the scientific traveler was to *see*; seeing was associated with knowledge,[23] Cavendish's first interest, always.

The journals are written in three different hands. One is Cavendish's, hastily written on the trips. Another is a copyist's. The copyist left blank spaces where he could not make out the words in the original; in the copy, missing and misread words are supplied in Cavendish's handwriting. The third hand is Blagden's. The Blagden papers in the Beinecke Library at Yale contain a journal of the second half of Cavendish and Blagden's journey of 1787, written by Blagden. A comparison between it and the copyist's journal in Cavendish's papers at Chatsworth shows that Blagden's journal is the source of the copyist's. Words crossed out in Blagden's journal do not appear in the copy, and illegible words are misread or left out. Cavendish kept a journal of the first half of the 1787 journey. He and Blagden wrote about the same kinds of things and in the same plain, factual style.[24] They agreed on what to record, which would have been Cavendish's to decide.

A person who helped make arrangements for one of their journeys called it a "philosophical tour,"[25] which it was, though they called it simply a "journey." Their journeys had a twofold purpose: to observe the heights and geology of the island and to observe the machinery and processes of industry. The journeys took place on three successive years, always in the summer months when the roads were good. The first, in 1785, took them to the west of London, to South Wales; the second to the north of London, as far as Yorkshire; and the third to the southwest of London, to Cornwall.

Cavendish had long been a vicarious traveler. In addition to drawing up scientific instructions to observers who undertook voyages of discovery, he was an avid buyer and reader of books by travelers, and he invited travelers to meetings of the Royal Society and to dinners at the Royal Society Club. He recommended ten travelers for membership in the Royal Society; because he did not recommend many persons, the number shows a strong interest.[26] He valued the information that travelers brought back with them, and in the 1780s he himself became a traveler bringing back first-hand information.

Cavendish had made a few early trips. He traveled to Cambridge to pursue his education, and he traveled to the Continent with his brother. In 1778, he made a 6-day circuit through Oxford, Birmingham, Towchester, St. Ives, Ely, and back to London, making trials of Edward Nairne's magnetic dipping needle at every stop, evidently the point of the journey; he had recently reported on the Royal Society's

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[23] Barbara Maria Stafford, *A Voyage into Substance: Art, Science, Nature, and the Illustrated Travel Account, 1760–1840* (Cambridge and London: MIT Press, 1984), 52.

[24] Charles Blagden, untitled journal of the second half of the journey of 1787, Yale, box 1, folder 2. Copy of the same, and Cavendish's journal of the second half of the journey, Cavendish Scientific Manuscripts, Chatsworth, X(a), 6 and 7.

[25] George Hunt to Mr. Hext, 23 January 1787, Blagden Papers, Yale, box 1, folder 4.

[26] The travelers Cavendish recommended are identified in Jungnickel and McCormmach, *Cavendish* (1999), 261–65.

meteorological instruments including its dipping needle made by Nairne.[27] A short journey from London to Folkstone on the English Channel, passing through Maidstone, Ashford, and Hythe, can be mapped from a list of stones he brought home to examine.[28] In the journal of his journey with Blagden in 1787, Cavendish wrote that the road from Bath to Devises had been changed since he was there "on a former journey,"[29] about which we have no further information. He may have made other trips for which he did not leave a record, but the journeys of the 1780s were unusual for their range and objectives.

What do we make of Cavendish's adventurous turn in midlife? On first thought, there seems to be a contradiction here. Travel entails an interruption of routine, and this man of inflexible habits voluntarily makes a sudden appearance as a repeating tourist. The explanation lies in part in the nature of the journeys: intended as an extension of his studies of the physical world, they continued the essential routines of his life. It lies in part too in the kind of tourist he was. He minimized the disruption of his life by bringing its essentials with him. He traveled with the man who was with him on a daily basis, Blagden; he brought a servant; he brought instruments and a portable laboratory and pen and paper to record his observations. It helped too that the journeys were planned well in advance. Persons who provided extended hospitality were not complete strangers. For example, in preparation for Cavendish and Blagden's journey to Cornwall in 1787, an acquaintance of theirs in the Royal Society, Roger Wilbraham, wrote to George Hunt, a Whig Member of Parliament from Cornwall, to introduce Cavendish and Blagden, both "well known in the literary world," to Mr. Hext in Cornwall who was asked to be of "service to them in the mineral way." If Mr. Hext were to take them to Lanhydrock, Hunt's home, he should get them a good mutton dinner and produce the marked "old" port and sherry from his cellars.[30]

On the journeys, Cavendish was the person we recognize from Wilson's description: from his monk cell's "narrow window he saw as much of the Universe as he cared to see."[31] His window was narrow, but less narrow than we might imagine. His interest remained the physical world, but we learn that this embraced a wide range of industrial processes and machinery. The extension of his interest could be direct. When C. J. Phipps, Lord Mulgrave invited Cavendish to visit his alum works, Cavendish was receptive to the idea, "having formerly made experiments himself on the crystallization of alum."[32]

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[27] Henry Cavendish, "Trials of Nairne's Needle in Different Parts of England," Cavendish Scientific Manuscripts, Devonshire Collections, Chatsworth, IX, 11.

[28] Henry Cavendish, "List of Stones with Their Examination," Cavendish Scientific Manuscripts, Devonshire Collections, Chatsworth.

[29] Cavendish, Journal of 1787, p. 6.

[30] Hunt to Hext, 23 January 1787.

[31] Wilson, *Cavendish*, 186.

[32] Charles Blagden to Lord Mulgrave, 2 August 1786, draft, Blagden Letterbook, Royal Society 7: 17.

In his daily life, Cavendish preferred continuity to novelty, but he was open to new vistas on his travels. Blagden told a friend in Bristol that he would try to persuade Cavendish to stop there on their way home from a journey, but he was not hopeful. Because Cavendish had already been to Bristol, he would want to return by a "new road."[33] As in the laboratory, where Cavendish was drawn to novel behaviors of matter as a matter of course, on the journeys he was drawn to terrains, machines, materials, and processes that were novel to him. These he found sufficiently interesting to draw him repeatedly from the sameness of his London life to life on the road.

After industry, the next most common subject of Cavendish's travel journals is geology, the first we learn of his active interest in this science. The leading problem of the day in geology was the succession of strata in Britain,[34]and his journals contain extensive observations of strata. At least part of the reason he took up geology was his recent interaction with John Michell, the natural philosopher most knowledgeable about British strata. Cavendish made a point of visiting him on one of his journeys.[35]

Very occasionally, entries in the journals stray from the objects of the journeys. Cavendish and Blagden learned that a canal had not yet paid any dividends, and that the rate for bringing coals up it was three shillings a ton.[36] This lonely economic fact appears in the journal for 1785. The town of Bridgenorth [Bridgnorth], which rose high above the River Severn, received all of its water from a wheel-work in the river that turned with the current, and there was no fall in the river there other than that produced by stopping the current in that part.[37] They passed through many towns in 1785, but this is the only town that is commented on (Fig. 10.1).

The same journal contains two passages in striking contrast to the factual observations surrounding them. At an ironworks, the scoria was "beautifully veined with white and blue." This was definitely an aesthetic appreciation, for when the scoria looked like this, the iron was extremely bad.[38] The second passage is: "The Terras-walk commands a remarkable scene, from the singular appearance of these rocks all around, but especially on the opposite side of the River Severn, the Eastern, and from the fine view of the River underneath. The remains of the old Castle, battered by Oliver Cromwell, exhibit a remarkable instance of a leaning Tower, or ruin, which produces a fine effect."[39] When Wilson read this passage, he paused. To this point in the journal, he said, Cavendish had not said a word about "the grandeur of natural scenery – the changing aspects of the skies – the striking differences between

33 Charles Blagden to William Lewis, 11 July 1787, draft, Blagden Letters, Royal Society 7: 338.

34 Roy Porter, *The Making of Geology: Earth Science in Britain, 1660–1815* (Cambridge: Cambridge University Press, 1977), 119.

35 Charles Blagden to John Blagden Hale, 14 September 1786, draft, Blagden Letters, Royal Society 7: 33.

36 The journal is in a wrapper labeled in Cavendish's hand, "Computations & Observations in Journey 1785," Cavendish Scientific Manuscripts, Devonshire Collections, X(a), 4, p. 8. Hereafter cited as Journal of 1785.

37 Cavendish, Journal of 1785, 56–57.

38 Ibid., 55.

39 Ibid., 56.

Fig. 10.1 Bridgnorth. Photograph by Pam Brophy. The Shropshire town in 1998 (Wikimedia Commons)

Fig. 10.2 Bridgnorth Castle. Photograph by Philip McCavity in 2008. The twelfth-century castle was a Royalist stronghold in the Civil War. Cromwell took the castle and ordered it destroyed. Part of the great tower now leans at an angle of fifteen degrees, four times the angle of the leaning tower of Pisa (Wikimedia Commons)

the inhabitants of different parts of a region – the historical associations inseparable from certain localities, and much else, on which Saussure, Humboldt, Dalton, Darwin, Forbes, and other scientific pilgrims, expatiate so largely." The singular passage above, Wilson said, "infuses vitality and a human interest into these formal diaries; and shows that their writer had deep down in his nature, the common sympathies of humanity" (Fig. 10.2).[40] Wilson assumed that the journal was written by Cavendish, though he must have recognized that it was not in his handwriting.

Before we accept Wilson's conclusion about Cavendish's "common sympathies of humanity," we need to consider his traveling companion, Blagden, who we know was the actual writer of the journal. On their journey the next year, Cavendish and Blagden each kept a journal. Blagden's, which was in the form of a diary, was not copied out for Cavendish. Both Cavendish's and Blagden's journals contain observations of stones, but there the similarity ends. In his journal, Blagden commented freely on the natural beauty and the people of the regions they passed through. From the road near Thornhill, they had a "most beautiful" prospect both ways. On the road from Keighly to Halifax, the country looked "dull and gloomy," but on the approach to Halifax, there were "many fine prospects" again. Around Halifax, the people had good complexion and spoke the "most difficult language to understand" he had heard.[41] To Banks, Blagden wrote that in the Lake District, "Winander Meer [Windermere] is a most beautiful piece of water, & the scenery about it both magnificent & beautiful, according to the different positions." By contrast with Lake Windermere, the largest natural lake in England, Derwent Water looked "diminutive among the lofty mountains."[42] Between Windermere and Kendal, Cavendish wrote in his journal, the "prevailing stone was slate but with limestone in places," the limestone lasting all the way to Settle in north Yorkshire. Near Buttermeer Lake, wherever strata of slate were visible, the slate was "nearly perpendicular, and the hills were steep and regular in slope, covered with grass."[43] That was what Cavendish saw in the Lake District worth recording. His description gives the reader a picture without the subjective commentary.

Fifteen years later, Blagden came as close as he ever did to criticizing Cavendish in writing. To a friend, he wrote, "When I went to the lakes it was in company with Mr. Cavendish, who had no curiosity for several things which it would have given me great pleasure to have seen. Winander More struck me as the *prettiest* piece of

[40] Wilson, *Cavendish*, 179.

[41] 1 September 1786, Blagden Diary, Osborn Shelves, Yale, fc16.

[42] Charles Blagden to Joseph Banks, 4 September 1786, British Library, Add Mss 33272.

[43] Henry Cavendish, "Computations & Observations in Journey 1786," Cavendish Scientific Manuscripts, Devonshire Collections, Chatsworth, X(a), 3, p. 6. This part of the journal is in Cavendish's handwriting. The other part of the journal is in the copyist's handwriting and deals with Cavendish and Blagden's visit to Lord Mulgrave's alum works. This part does not appear in these footnotes.

water I had ever beheld."[44] For Blagden, the scientific objects in the scene were part of a larger view of the landscape, which included natural beauty. For Cavendish, the scientific objects were the only view of interest and the point of the journey. Not long after Cavendish and Blagden visited the Lake District, the poet William Wordsworth settled there to work on his theory of poetry, which would go in the preface of an edition of *Lyrical Ballads*, usually considered the beginning of the English Romantic movement in literature. In their responses to nature in the setting of the lakes, Cavendish with his strict objectivity is at one end of a spectrum, Wordsworth with his individual personal emotion is at the other end, and Blagden with his inclusive interests spans the middle. The passage in the 1785 journal about the fine view of the river and the fine effect of the castle could have arisen from a conversation on the trip, Blagden remarking on the prospect before their eyes, and Cavendish agreeing. In support of this possibility, Blagden said of their return journey from Cornwall by the north of Devonshire in 1787 that he took "great pleasure in shewing to Mr. Cavendish" the "grand beauties of that remarkable coast."[45]

There had long been interest in developing a reliable method of measuring heights of mountains using the variation of atmospheric pressure with elevation, as recorded by a barometer, but it was not until the 1770s that this method of measuring heights promised any degree of accuracy. The method was tried on Phipps's voyage in 1773. Heights were measured two ways: geometrically, using a theodolite, and barometrically, making use of André De Luc's rules for corrections. As measured by the theodolite, the height of a mountain was found to be 1,503 ft above sea level; as measured by the barometer, 1,588 ft. The discrepancy was considered large, and Phipps could not account for it.[46] There were alternative rules to De Luc's, and Cavendish compared them, drawing on his father's experiments on the specific gravity of air at different temperatures and pressures.[47] During the period of Cavendish's journeys, barometric heights were repeatedly taken on Mont Blanc, the highest mountain in the Alps.[48] They suggested to Cavendish an experiment on temperature corrections to barometric readings, and on his journey in 1787 he set up a meteorological station on Dartmoor, arranging for local persons to record instrument readings over a period of time after he left. Cavendish's interest in the barometric method was an extension of his long interest in meteorological instruments, and it bore on his new interest, geology, which deals with relief features of the

[44] Charles Blagden to Lord Palmerston, 25 November 1800, Blagden Letters, Yale.

[45] Charles Blagden to Mrs. Grey, 28 August 1787, draft, Blagden Letters, Royal Society 7: 351.

[46] Phipps, *Voyage to the North Pole*, Appendix.

[47] Henry Cavendish, "Rule for Taking Heights of Barometers," Cavendish Scientific Manuscripts, Devonshire Collections, Chatsworth, VIII, 12.

[48] From observations made by others, Cavendish calculated the height of the mountain. Charles Blagden to Joseph Banks, 5 October 1786, British Library, Add Mss 33272, pp. 19–20.

earth.[49] The barometric method of measuring heights became a major object of study for Cavendish for several years. The expectation was that if the right rules could be found, measuring heights by the barometer would become a practical and reasonably accurate method.

Cavendish and Blagden regularly made another kind of measurement. Cavendish had long suspected that the mean temperatures of different climates could be determined by taking the heat of springs and wells. If the rule held up, it would provide a convenient method of comparing the average temperatures of different climates not just in England but around the world.[50] In 1775, he advised Blagden to make observations with that view in mind in North America, where he was posted as an army surgeon during the American War of Independence. Blagden and Cavendish measured the temperature of wells and springs on their journeys in 1785–87. In 1788, a paper was presented to the Royal Society reporting the temperature of a well slightly above what was judged to be the mean heat of that part of Britain. In discussing the discrepancy with Blagden, Cavendish thought that the explanation lay in the stratum of clay in which the well was dug and on which London is built. To determine if London wells were too warm, Cavendish built a bucket that could be lowered to any depth, and he and Blagden tried it on several wells. To understand the facts better, Blagden studied the strata of Great Britain in a paper on the heat of springs and wells found among his scientific manuscripts.[51] Like the height of mountains, the heat of wells and springs related to geology, a leading interest of theirs on their journeys and after.

On all three journeys, Cavendish and Blagden brought with them a portable barometer for measuring heights. On their second journey, something went wrong with it, placing in jeopardy a main object of the journey. They appealed by letter to Banks, who asked the instrument maker Jessie Ramsden to send them one of his

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[49] Charles Blagden to William Farr, 12 June and 3 July 1787, drafts, Blagden Letters, Royal Society 7: 67 and 7: 335.

[50] "In England the heat of the water in deep wells or quick springs is very nearly equal to the mean heat of the air, and it seems well deserving inquiry whether it is the same in other countries; for if it is so, it would afford the readiest way of comparing the mean heat of different climates." "Meteorological Observations at Madras," extract of a letter by Cavendish, in Cavendish, *Scientific Papers* 2: 394. John Hunter, who became Cavendish's physician at some stage, was sent to Jamaica in 1782 to superintend a military hospital, and Cavendish suggested to him, as he had to Blagden when he journeyed to North America, that he observe the heat of springs and wells while he was there. Hunter published his observations in the *Philosophical Transactions* in 1788, where he gave a full account of Cavendish's hypothesis: assuming that the heat of the earth comes entirely from the sun, not from the earth's interior, measurements of temperatures deep enough inside the earth to remain constant through the seasons ought to yield the mean temperatures of different climates. A few observations of this nature would tell as much about average climates as years of meteorological observations. John Hunter, "Some Observations on the Heat of Wells and Springs in the Island of Jamaica, and on the Temperature of the Earth Below the Surface in Different Climates," *PT* 78 (1788): 53–65, on 53, 58, 65.

[51] Draft of a long paper by Blagden beginning, "The idea of determining the mean temperature of different climates by the heat of the springs and wells." Blagden Papers, Yale, box 6, folder 26.

barometers. When they received it, it was poorly packed, air had got into it, and it was a week late, causing Blagden to exclaim, "Ramsden, as usual, told a bounding lye, & that of the most impudent kind."[52] None of this actually mattered, since in the meantime they had fixed their own barometer. They took the normal travelers' inconveniences in stride, but a faulty instrument for measuring heights was serious. Their daily readings of the barometer and thermometer do not appear in the journals, but they are recorded and analyzed on separate sheets.

Their travels were physically demanding. Midway through their first journey, Blagden reported to Banks that they had measured the "highest mountains" in four counties, having climbed them with their barometer.[53] On their second journey, they were shown a lead mine by the proprietors, who were quite willing to take them further than they wished to go. They found climbing up and down the ladders "very fatiguing work," especially Blagden whose legs were "scarcely long enough to straddle across some of the wider turns."[54] These and other physical discomforts of their travels are never mentioned in the journals.

Reports from senses other than sight are rare in the journals. At a tinplate works, they saw how rust was beaten off iron plates, "struck with great violence by a man on an iron Anvil."[55] The journal does not mention the sound of that activity or that of the hammers and other machinery, which would have been tremendous. They saw finers at their forges exposed to searing temperatures. Unaccustomed to the intense heat, Cavendish and Blagden would have kept their distance, but the journal makes no mention of the heat on their skin. The journal is limited to the matter-of-fact recounting of how things worked and looked and occasionally smelled.

Cavendish was fortunate in his companion, a committed traveler. Blagden had made journeys all his life and had kept a record of them. At age 17, he traveled from London to Scotland to study at the University of Edinburgh. In a letter to a relative, he described the roads on that journey, gave the distances traveled each day, reported the weather, and mentioned the sights: a hose manufactory, a castle, a river, and prospects, beautiful and barren.[56] At age 18, he took a 6-day vacation from his studies to take a journey on foot of some 80 miles, "undertaken chiefly with a view to philosophical curiosities," but which included cobalt mines and the "finest ironworks in Scotland."[57] Several months later he took a "short jaunt" in the Highlands.[58] Everything was interesting to the serious young traveler, who had disdain for people

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[52] Charles Blagden to Joseph Banks, 13 and 19 August, 4 September, 1786, British Library, Add Mss 33272, pp. 1–2, 7–8.

[53] Blagden to Banks, 31 July 1785.

[54] Charles Blagden to Joseph Banks, 17 September 1786, British Library, Add Mss 33272, pp. 9–10.

[55] Cavendish, Journal of 1785, 19.

[56] Charles Blagden to Sarah Nelmes, 1 November 1765, Blagden Letters, Royal Society, B.159. Blagden's great aunt, Sarah Nelmes was a spinster living in Bristol.

[57] Charles Blagden to Sarah Nelmes, 26 March 1767, Blagden Letters, Royal Society, B.161.

[58] Charles Blagden to Sarah Nelmes, 19 September 1767, Blagden Letters, Royal Society, B.161a.

who were satisfied with their "little world," incurious about what lay beyond it.[59] Journeys were an opportunity to observe the greater world. William Cullen, Blagden's professor in Edinburgh, warmly recommended him, noting he had "more knowledge than most of his standing."[60] Hannah More after meeting Blagden at a small select party called him "a new bluestocking, and a very agreeable one," who is "so modest, so sensible, and so knowing, that he exemplifies Pope's line, 'Willing to teach, and yet not too proud to know.'"[61] He had a remarkable and accurate memory. James Boswell and Samuel Johnson talked about his "copiousness and precision."[62] He had the right qualifications for Cavendish's daily associate. To the point here, he was interested in the industrial scene.

Blagden was interested in people too. Upon his return from North America, in 1781 he settled in London, where he sought out the company of men of science. The following year, as we know, he became Cavendish's associate, and 3 years after that he became Cavendish's traveling companion. He readily adapted to persons of different stations and temperaments. In his youth he advised a friend to read Jean-Jacques Rousseau, "the most eloquent & feeling of men,"[63] and in middle age he paid homage to the most romantic scene of Rousseau's novel *La Nouvelle Heloïse*,[64] and he went on an extended journey to observe ironworks with a man he described as having no affections. He willingly accepted Cavendish's ways and deferred to his desires. There is no reason to think they had serious collisions, and harmony being the condition of successful travels, we suppose that they pursued their goals without personal distractions. Evidence of this is that after their first journey, they took two more.

The goals of the journeys were Cavendish's, and he chose well. Grounded in his interests, the goals were realistic, and within the limitations of the weather they were all met. On their departure from Wales in 1785, Blagden wrote to Banks that Cavendish "bears the journey remarkably well."[65] When they returned from their journey to Cornwall in 1787, Blagden wrote to Banks that Cavendish "is very well, & I think looks the better for his journey."[66]

When Blagden said that Cavendish always knew what was right for him, he may have had the journeys in mind, among other things. Around the time of the journeys, Cavendish made several major changes in his life, which are discussed in Chap. 8. We briefly recall them here to add to them a major change in his scientific work.

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[59] Charles Blagden, "Memorandum of a Tour Taken for Four Days Beginning August 18, 1771," Blagden Papers, Yale, box 1, folder 3.

[60] John Thomson, *An Account of the Life, Lectures, and Writings of William Cullen, M.D.*, vol. 1 (Edinburgh and London, 1859), 555–56.

[61] Hannah More in 1788, quoted in Crowther, *Scientists*, 333.

[62] Johnson found Blagden a "delightful person." James Boswell, *The Life of Samuel Johnson, LL.D. …*, rev. ed., 5 vols. (London, 1821) 4: 309.

[63] Charles Blagden to Thomas Curtis, 26 July 1771, draft, Blagden Letters, Royal Society, B.162.

[64] Blagden, "Diary of Sir Charles Blagden," 77.

[65] Blagden to Banks, 31 July 1785.

[66] Charles Blagden to Joseph Banks, 14 August 1787, British Library, Add Mss 33272, p. 35.

The first change was his willingness to take on an associate. Blagden was not one of his young assistants but a well-educated physician and officer of the Royal Society who made a scientific career for himself. The second was location. In 1782, the year he began his association with Blagden, he took a house in Hampstead. The next year his father died. In 1784, he bought a townhouse on Bedford Square, which he largely converted into a library. In 1785, the year of his and Blagden's first journey, he moved into a substantial villa near Clapham, which he largely converted into a laboratory and observatory, and where he would remain to the end of his life. A third major change was the direction of his scientific work. Except for an answer to criticism in 1788, he finished publishing his work in the chemistry of airs (gases) in 1785. Not long after that, he drafted a mechanical theory of heat, which brought together his extensive researches on the subject. His experiments on heat, which had paralleled his work on chemistry from the start of his career, came to an end with publications in 1786 and 1788. His work on electricity, the third field in which he had done important work, had come to an end somewhat sooner, in the early 1780s. In his 50s, having nearly completed his work in the major fields, he was open to a new direction, and his journeys, themselves a major change, pointed the way. He was at an age when men often undergo life changes, but if that was the case with Cavendish, the significant changes were contained within his life of natural philosophy.

In 1786, the second year of his journeys, he began recording his chemical experiments in a book of blank pages; this was the permanent record, transcribed and rewritten from the rough "minutes" of the experiments. He labeled it "White Book, No. 1," suggesting an open-ended subject. In it, he referred to a "2d book," perhaps "White Book No. 2," since lost. The White Book contains some experiments on air, but this was no longer a focus of his work.[67] The new format signaled a change in

[67] After 1786, the year Cavendish opened his White Book, he added some more pages of experiments to a massive bundle of pages, "Experiments on Air," the record of a sustained series of interconnected chemical researches, which contain his experiments on the production of water from the detonation of oxygen and hydrogen, the nature of nitric acid, and the composition of the atmosphere. The later experiments did not have a comparable direction, and there is no indication that he had publication in mind for any of them. They do include an impressive investigation of the expansion of different kinds of air with heat, which determined that within the limits of accuracy of the experiments the coefficient of expansion is the same for all of them, but these experiments are out of place in the bundle, being physical not chemical. They are undated, but as they are recorded on paper bearing a 1797 watermark, they could not have been performed before that year. They appear to be Cavendish's last important research on airs. There are later pages containing small investigations having to do with airs. In light of the great changes chemistry underwent in the late eighteenth century, the most interesting of these is a reconsideration. Writing on paper watermarked 1800, Cavendish returned to experiments he had carried out probably in late 1783 on the nature of charcoal produced by burning willow wood. He carried out computations on the earlier experiments and drew a conclusion, which he expressed partly in the new language of chemistry: "either that charcoal contains hydrogen as well as carbon & water or else that the charcoal after distillation contained some oxygen. There is no reason to think the charcoal yielded any phl[ogisticated] air." The subject of the experiments and their timing point to a likely reason for his uncharacteristic use of the new nomenclature of chemistry in 1800. At the end of his paper, "Experiments on Air," read to the Royal Society in January 1784, where he says it would be very

the direction of his research, one which continued the contacts he had made in the course of his journeys in the country beyond the metropolis. Many of the entries could be called geological and industrial experiments, though mineralogical experiments would be appropriate too, since in the eighteenth century ores and stones were both considered mineral. Many experiments dealt with specimens from industrial processes and mines, which Cavendish either brought home from the journeys, or were sent to him from persons he met on the journeys, or were given to him by colleagues. The specimens included industrial discards such as kish from iron furnaces, slag from the purification of copper, cinder from fineries, and dust from lead smelting furnaces. Byproducts of industrial processes, they held chemical clues to what went on in the furnaces and were interesting scientific objects in themselves. On his second journey, Cavendish made side trips in search of kish, a black shiny matter that came down into the hearths of iron furnaces and was thought to reduce the quantity of iron and also to give iron certain qualities when mixed with it. William Lewis, whom he and Blagden visited, and other ironmasters had not mentioned it, and on his return Cavendish requested information about it and samples to be sent to him.[68] Through his travels, Cavendish widened his active field of interest in ways he would follow up at home.

Wilson was disappointed that Cavendish's travel journals lacked human interest. Cavendish's editors excluded them because they contained nothing of geological importance, and "as narratives of travel they have no particular value," nor do they "afford any special information" about technical and manufacturing operations. They also excluded Cavendish's paper on strata, which drew on observations he made on his journeys, because it had no geological importance and would not enhance his reputation as a geologist.[69] We look at them differently, for what they tell us about Cavendish. They tell us that he journeyed through unfamiliar physical and human surroundings, seeing and recording objects that were new to him. They confirm what this natural philosopher asked of life: to provide him with meaningful physical objects to study.

Crowther saw value in Cavendish's travel journals. Given Cavendish's social background and his "reserved London life," he found them "remarkable," revealing "a keen and penetrating interest in the applied science of the new industry" and a

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difficult to decide between the chemistry of phlogiston and the new chemistry from France, he says that he prefers the old chemistry because of plants, which seem to him to be more compounded than the charcoal or ash to which they are reduced upon being burnt. According to the new chemistry, a plant is deprived of dephlogisticated air (oxygen), and upon burning it acquires it. The plant is simpler than the ash. According to the old chemistry, the plant contains phlogiston (hydrogen, or related to hydrogen), which is given up when it is burnt, making it more compounded than the ash. "Experiments on Air," Scientific Manuscripts, Devonshire Collections, Chatsworth, II, 5: 251–65, 386–90, quotation on 390. "Experiments on Air," *Scientific Papers* 2: 181.

[68] Charles Blagden to William Lewis, 26 September 1786, Blagden Letters, Royal Society 7: 38. Kish is a form of graphite that separates from some iron in smelting. Plumbago and black lead are other names for the graphite. In 1779, Scheele showed that plumbago is essentially carbon, perhaps the reason for Cavendish's interest.

[69] Evaluations by Thorpe and Archibald Geikie in Cavendish, *Scientific Papers* 2: 431–32.

watchful interest in geological formations of potential interest to mining.[70] To better understand what drew Cavendish to ironworks and mines, we look at him in his familiar setting, the scientific society in London at the time. Many of its members had a strong interest in applications of natural philosophy and chemistry to industry. We see this in the record of a club that met in a London coffee house in 1780–87, the period of Cavendish's journeys: the [Chapter] Coffee House Philosophical Society. Cavendish did not belong to the Society, but he knew many of those who did. They included his customary instrument maker Nairne; Priestley, with whom he had a chemical correspondence; the chemist and scientific polymath Kirwan, with whom he had a public disagreement about a serious point in chemistry; the inventor Watt, an honorary member whom he visited on his journey in 1785; John Hunter, who was Cavendish's physician; the chemist James Lewis Macie (James Smithson), who worked as Cavendish's assistant for a time; and a number of other well-known men of science, medicine, and industry such as the manufacturer and engineer Boulton, the industrial chemist James Keir, the ceramics manufacturer Wedgwood, and the geologist and clockmaker John Whitehurst. The majority of members were fellows of the Royal Society.[71] In 1785, the year of his first journey, Cavendish recommended Watt and Kier for membership in the Royal Society, clear indication that he wanted the Royal Society to recognize the industrial development of science, as he himself did.[72]

The Coffee House Philosophical Society is rare among scientific clubs in leaving a detailed record of its meetings. At its founding, the Society resolved that its conversations "shall be confined to Natural Philosophy, in its most extensive signification." From the minutes of the Society, we see that its conversations were, as intended, about natural philosophy, chemistry, industry and applied science, meteorology, ballooning, and a few other subjects. Among the topics that came up at the meetings were a device for measuring the expansive power of steam, a machine for welding masses of iron together by pressure, chemical differences between the forms of iron and steel, and hammers driven by steam engines in ironworks. Chemistry was the leading scientific subject of the discussions, and in 1785 the question of the existence of phlogiston, the central idea of the older chemistry, then under attack by French chemists, was first raised. During the years of his journeys, Cavendish's interests in industry and chemistry paralleled those of members of the Society, and his interest in geology paralleled discussions of ores in the Society.[73]

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70 Crowther, *Scientists in the Industrial Revolution*, 320.

71 G. L'E. Turner, "The Membership," in *Discussing Chemistry and Steam: The Minutes of a Coffee House Philosophical Society, 1780–1787*, eds. T. H. Levere and G. L'E. Turner (Oxford, New York: Oxford University Press, 2002), 17–44.

72 Priestley, Smeaton, and Cavendish were the first signers of the certificates for James Watt, elected 24 November 1785, and for James Keir, elected 5 December 1785. Certificates, Royal Society, vol. 5.

73 T. H. Levere, "Introduction," in *Discussing Chemistry and Steam*, 1–15. Jan Golinski, "Conversations on Chemistry: Talk about Phlogiston in the Coffee House Society, 1780–1787," ibid., 191–205, on 193–97.

When Cavendish visited the industrial Midlands on his journey in 1785, he met several members of the Coffee House Philosophical Society on their home ground. They were also members the Lunar Society of Birmingham, a small club which met monthly at individual houses including Boulton's house at Soho.[74] It differed from the London club in having no written rules or records of meetings or formal membership. Its members were a mix of natural philosophers, inventors, manufacturers, and doctors, several of whose names appear in Cavendish's travel journals: William Withering, Watt, Wedgwood, and Whitehurst. The productivity of the club lay in the collaboration of men with strong talents, joined in the belief that science, industry, and progressive ideas would change the world for the better. The dates of the beginning and end of the Lunar Society are uncertain, but its most productive years were 1780–89, bracketing the years of Cavendish's journeys. The compositions and purposes of the London and Birmingham clubs show that there was nothing unusual in the interest Cavendish took in industry and geology on his journeys. His thinking was aligned with that of the most capable men of the age.

The list below is what Cavendish and Blagden chose to see and record on their journeys:

Air pumps.
Alum mine.
Alum production.
Bellows powered by waterwheel.
Blast furnace.
Brass making.
Button manufacture.
Canals.
Chafery.
Circular motion given to steam engines.
Clay pits.
Cloth manufacture and dyeing.
Coal pits and mines.
Coal tar production.
Coal, coke, and charcoal.
Coke production.
Copper and tin mines.
Copper, iron, and tin ores.
Copper smelting houses.
Cylinder boring mill.
Drilling mill.
File making.

[74] The society is the subject of Robert E. Schofield, *The Lunar Society of Birmingham: A Social History of Provincial Science and Industry in Eighteenth-Century England* (Oxford: Clarendon Press, 1963).

Filigree work.
Finery.
Flatting mills.
Forges.
Hammers operated by steam engines.
Iron mines.
Iron ore.
Ironworks.
Japanning copper.
Lead mine.
Limestone quarry.
Machine for twisting handles of horsewhips.
Nail manufacture.
Needle manufacture.
Parallel motion given to steam engines.
Pitch.
Quarries.
Reverberatory furnace.
Rolling mills.
Shingling.
Silver plate manufacture.
Slitting mills.
Stamping and Potting.
Steam engines.
Stones.
Strata.
Tides.
Tin and copper mines.
Tinplating.
Tunnel cutting for canals.
Water pumps operated by steam engines.
Waterwheels.
Wells.
Wire manufacture.

10.3 Working Iron

Iron was the most important natural element in the Industrial Revolution. In Britain, its production was concentrated in a small number of places, Welsh valleys prominent among them. Before joining Cavendish and Blagden on their journey into one of the valleys, for readers who are unfamiliar with the history of iron, it will be helpful to describe how it was produced in Britain at the time, drawing on today's

chemical knowledge and language.[75] Iron is plentiful, but in nature it rarely appears as pure iron. In the form of ore, iron is combined with oxygen in various proportions, and usually other elements are present in small quantities. The ore was reduced to the metal in an operation called "smelting," an old term Cavendish did not use, which required a high heat and a reducing agent containing carbon; in practice, the reducing agent was at the same time the source of the heat, either charcoal or coke. The carbon removed oxygen from the ore by combining with it to produce gases, carbon monoxide and carbon dioxide, which escaped through the top of the furnace. Left behind were elemental iron, some carbon, and chemical impurities such as sulfur, phosphorous, and silicon. The residual carbon had a useful function: for strength iron needed to contain a small quantity of carbon, the proportion of which determined whether the iron was suitable for making cast iron, wrought iron, or steel. Iron had to be separated from impurities as well as from oxygen, for which purpose limestone, called a "flux," was heated together with the ore. The flux also increased the fluidity of a partially vitreous byproduct of smelting, "scoria," or slag, a mix of impurities, cinders, and the added flux, enabling the scoria to be tapped from the bottom of the hearth; the term "flux" derives from this fluidity.

Two kinds of furnaces were used in smelting, the "blast furnace" and the "forge." Iron ore together with limestone and fuel were placed in the hearth of a blast furnace and heated to a high temperature, while air was blown through it by a bellows or an air pump, driven by a waterwheel or steam engine. Molten iron tapped from the corner of the hearth was called "pig iron," the name deriving from the traditional method of forming manageable pieces of solid iron: molten iron from the blast furnace flowed into depressions in sand, forming paired rows of iron ingots at right angles to a central channel, suggesting a litter of suckling piglets. Pig iron could be used to make "cast iron," or iron poured into shaped molds, but because it contained excess slag and carbon it could not be used directly to make malleable or "wrought iron." Pig iron could be shaped by hammering when hot, but once it cooled hammering would crack or break it. Because it had a crystal structure, it was strong in compression, and so it was useful in making bridges and other structures.

Wrought iron had a low carbon content and a fibrous structure, making it tough and malleable, capable of being hammered or rolled. Today wrought iron is not made commercially, and what is called wrought iron is really steel that is hand-worked, but in the eighteenth century wrought iron was the main form of iron, valued because it could be shaped.[76] To make it, the pig iron underwent a second round

[75] Much of this and the following five paragraphs on iron production in Britain are based on H. R. Schubert, "Extraction and Production of Metals: Iron and Steel," *History of Technology*, vol. 4: *The Industrial Revolution, c1750 to c1850*, ed. C. Singer, E. J. Holmyard, A. R. Hall, and T. I. William (New York and London: Oxford University Press, 1958), 99–117. Laurence Ince, *The South Wales Iron Industry 1750–1885* (Merton: Merton Priory Press, 1993). Richard Hayman, "The Shropshire Wrought-Iron Industry c 1600–1900: A Study of Technological Change," PhD thesis, University of Birmingham 2003.

[76] Wrought iron remained the usual kind of malleable iron until the late nineteenth century, when mild steel became practical. The steel that was made in the eighteenth century had limited uses such as files.

of smelting in a “finery forge,” which was a small furnace for refining the impure iron. In the forge, the pig iron was placed on a hearth containing fuel, reheated, and stirred by a finer handling a long iron bar, while air was blown on it. The fuel was charcoal, because a mineral fuel, coal or coke, in contact with the molten iron would reintroduce impurities. The operation removed much of the remaining carbon, silicon, and other impurities by oxidation. The product was a porous lump of iron known as the “half-bloom,” its pores being filled with slag. To make the lump more compact, it was placed on an anvil under a massive trip hammer, powered by water or steam. Then it was usually returned to the finery forge, and reheated. To drive the molten slag from its remaining pores, and also to knock off slag adhering to the surface, the reheated half-bloom was beaten with a hammer. This consolidation of the iron by hammering was called “shingling.” The hammer-man’s work was potentially dangerous, since with each blow of the hammer white hot slag flew across the room. Finally, the iron was taken to a second forge, a “chafery,” where it was reheated until it was just malleable, and it was then hammered into a bar of wrought iron, known as “bar iron,” ready for use. Because the iron in the chafery was not heated to the melting point, coal could be used as fuel without danger of its impurities entering the iron. The finery and chafery forges were usually housed in a large wooden shed, along with trip hammers, hand hammers, anvils, tongs, carts, and other tools for moving hot, heavy pieces of iron.[77] The words in quotation marks above are ones used in the journal.

The production of iron underwent several major changes in the second half of the eighteenth century. One was a partial change of fuel. Charcoal, a fuel obtained by heating wood, was almost pure carbon, excellent for reducing iron ore to the pure metal. A problem with it was that British forests were being depleted to make charcoal for blast furnaces, which consumed it in prodigious quantities. Naturally there was an interest in finding a practical substitute. Coal, another good source of carbon, was plentiful and relatively cheap, and attempts were made to use it in place of charcoal, though its impurities resulted in a weak iron. Coke, obtained by heating soft coal, was cleaner. Introduced in Britain at the beginning of the eighteenth century, coke came into wide use for blast furnaces in the second half of the century.[78] Coke was less friable than charcoal, and accordingly furnaces could hold larger charges of ore and stronger blasts could be used, resulting in greater production. The disadvantage of coke was that it contained more impurities than charcoal, for which reason charcoal continued to be preferred for most finery forges. A second important change was the replacement of water power by steam power for some purposes. The first use of the steam engine for a purpose other than pumping water out of mines was to drive an air pump at John Wilkinson’s blast furnace at New Willey in 1776. It was first used to raise water to turn a waterwheel for operating a

77 Anon., “Forge, Furnace, What’s the Difference?” http://www.engr.psu.edu/mtah/essays/forge_furnace.htm.

78 Five years after Cavendish and Blagden’s journey, 81 out of 106 blast furnaces in Britain were fueled by coke.

forge hammer at Wilkinson's ironworks at Bradley in 1782.[79] Cavendish and Blagden visited both of Wilkinson's sites, and they also visited the designer of Wilkinson's engines Watt at the Soho Manufactory in Birmingham. A third change was an increase in the production of cast iron for construction uses. On their journey, Cavendish and Blagden saw the Iron Bridge [Ironbridge], an early instance of cast-iron construction.

The final important changes were two inventions by Henry Cort, both leading to increased production. The first, in 1783, was grooved rollers for making iron bars, replacing slitting mills; the second, in 1784, was a process called "puddling," which converted pig iron into wrought iron in a reverberatory furnace, described below, without the use of charcoal; the molten pig iron in the furnace was stirred by long iron bars, which assisted the removal of carbon and impurities by oxidation. Over time, puddling replaced the finery process for making wrought iron. On their journey, Cavendish and Blagden saw neither of Cort's innovations, though they saw reverberatory furnaces, and South Wales was one of the earliest locations for puddling furnaces.[80] Later Cavendish took an interest in Cort's process for working pig iron. We know about it from notes he took of a conversation with the engineer James Cockshutt about the advantages and disadvantages of two variants of the process, one requiring a common coke finery in addition to a Cort's furnace, the other using only a Cort's furnace. Cockshutt gave Cavendish finery cinders corresponding to the two variants, which Cavendish subjected to chemical tests with his customary thoroughness.[81]

10.4 Journeys and Science

When Cavendish ventured into the wider world of industrial Britain, he saw a reflection of his own small world on Clapham Common. He visited forges, which differed from the forge at home mainly in scale. In the fiery hearths of ironworks, he saw chemical reactions releasing gases, which differed from what he saw in his laboratory mainly in scale. He brought the wider world back with him in the way of specimens from furnaces, forges, mines, and geological formations. A month after they returned from their second journey, Blagden wrote that Cavendish was busy making experiments on stones and on specimens from an alum works.[82]

In the time of his journeys, Cavendish's most important scientific work was in chemistry, and on his journeys the most important actions he observed were chemical. In 1785, 2 months before Cavendish and Blagden began their first journey,

[79] Harris, "Wilkinson," 1010–11.

[80] Schubert, "Extraction and Production of Metals," 99–107.

[81] The notes, dated spring 1793, are entered loosely in Henry Cavendish, "White Book No. 1," Cavendish Scientific Manuscripts, Devonshire Collections, Chatsworth. His experiments are on pp. 84–90.

[82] Charles Blagden to Joseph Banks, 8 [?] October 1786, British Library, Add Mss 33272, pp. 15–16.

Blagden wrote to a French chemist that the British had not yet given up on phlogiston but that with Cavendish it was a "doubtful point." The question of which hypothesis was right, that of phlogiston or that of Lavoisier's, "cannot remain long undecided."[83] In 1787, 2 months after their last journey, Blagden wrote to the same chemist that the main objections of the partisans of the doctrine of phlogiston had been answered, and that the explanations of Lavoisier's hypothesis were "so much clearer and more pointed" that the "combat must soon be at an end."[84] Blagden wrote as one convinced of the imminent victory of the new chemistry coming out of France. He was in regular correspondence with French proponents of the new chemistry, and he was in the regular company of a principal chemist of the old chemistry, Cavendish, who at the time was in serious doubt. We might expect Blagden's opinion on the great question of the day in chemistry to be aligned with Cavendish's. In the spring of 1787, before Cavendish and Blagden began their last journey, the Irish chemist and warm advocate of phlogiston Richard Kirwan wrote to a French chemist, "Mr. Cavendish has renounced phlogiston."[85] By whatever route Kirwan learned this, we have no reason to doubt him. Given what Cavendish wrote about the two chemistries in 1784 and what Blagden had told colleagues about Cavendish's views since then, Kirwan's news comes as little surprise. With reasonable confidence, we can say that Cavendish was the first British chemist to abandon the old chemistry centered on the concept of phlogiston.

Over the 2 years following Cavendish's last journey with Blagden, the French advocates of the new chemistry were elected foreign members of the Royal Society. Cavendish signed the certificates for all of them, and in the case of their leader, Lavoisier, he was the first to sign.[86] What was called "dephlogisticated air" in the old chemistry was renamed "oxygen" in the new chemistry, where it was regarded it as an elementary substance. The "phlogiston" of the old chemistry did not appear in the new chemistry. Of interest to us in this chapter is the timing. Cavendish's questioning and renunciation of phlogiston coincided with his journeys into an industrial heartland, where he observed chemical processes explained either by phlogiston or oxygen.

The processes of iron production he observed may have played a supporting role in his change of mind on the foundations of chemistry. According to the new chemistry, the principal object of smelting was to remove oxygen from the iron in the ore; according to the old chemistry, it was to add something, phlogiston. In the ironworks Cavendish visited, and in his laboratory where he experimented on specimens from the ironworks, he had frequent occasions to consider the question of

[83] Charles Blagden to Claude Louis Berthollet, 21 and 24 May 1785, drafts, Blagden Letterbook, Yale.

[84] Charles Blagden to Claude Louis Berthollet, 17 November 1787, draft, ibid.

[85] Richard Kirwan to Guyton de Morveau, 2 April 1787, in *A Scientific Correspondence during the Chemical Revolution: Louis-Bernard Guyton de Morveau and Richard Kirwan, 1782–1802*, ed. E. Grison, M. Sadoun-Goupil, and P. Bret (Berkeley: Office for History of Science and Technology, University of California at Berkeley, 1994), 165–67.

[86] Certificates, Royal Society, 5 (3 April 1788).

oxygen or phlogiston. What he saw at the ironworks did not answer the question any more than did his experiments on air, where he had addressed the question in the year before his first journey, but it directed his thoughts to it over a sustained period. Evidence of his thinking on the question is an undated draft of a paper, inserted loosely in the White Book, which Cavendish prepared for the engineer Cockshutt who had sent him specimens of iron and coal to examine. Cavendish wrote out for him a chemical analysis of the production of iron, with recommendations for practice. He addressed the variables in the operation of smelting – cast and wrought iron, charcoal and coal fuels, and hot and moderate temperatures – which he related to materials that enter the smelting process, slag, carbon, and oxygen, though he did not use these terms. He described the chemical difference between cast iron and wrought iron in both the old and the new chemistry: according to "Bergman & the partisans of phlogiston," cast iron contained less phlogiston than wrought iron, and according to "favourers of the new system," it contained some oxygen.[87] He did not say which explanation he preferred, but he acknowledged that the question of phlogiston and the two chemistries came up in the explanation of smelting, the point being made here.

The journeys may also have been a stimulus to Cavendish's work on heat. At the ironworks, he witnessed high heats produced by chemical reactions of the fuels, and he witnessed chemical reactions of the ores caused by the heats; and at some of the ironworks he witnessed steam engines in operation. From early in his career, he was convinced that heat is the vis viva (energy of motion) of the vibrations of the particles constituting bodies, but it was not until the late 1780s, the time of his journeys, that he worked out a theory of heat based on this understanding. The theory contained a derivation of the complete principle of the conservation of energy including heat. He wrote up the theory as a paper with publication in mind, but for unknown reasons he did not follow through with it. It would be 60 years before physics acquired a comparable mathematical-theoretical formulation of energy and heat. In his paper, Cavendish applied the theory to the heats of chemical reactions, heats of a kind he observed in the hearths of furnaces and forges. Where steam engines powered massive hammers and air blasts, he saw instances of the conversion of heat into mechanical work, as explained by his theory. In the working of steam engines, he saw the interconversion of water and steam, the heat of which was explained by his theory. He had worked out the parts of the theory much

[87] Henry Cavendish, "Paper Given to Cockshutt," loose insert in "White Book No. 1." He was probably the engineer James Cockshutt who was in charge of the forges at the Wortley Ironworks near Sheffield, and who co-managed the Cyfarthfa forge and mill for making cannon at the time Cavendish and Blagden visited there. About then, around 1787, Cockshutt together with a partner introduced Cort's puddling and grooved rolling processes at both Wortley and Cyfarthfa. In 1804 Cavendish recommended Cockshutt for membership in the Royal Society. Ince, *South Wales Iron Industry*, 60. *Biographical Dictionary of Civil Engineers in Great Britain and Ireland*, vol. 1: *1500–1830*, ed. A. W. Skempton (London: Thomas Telford, 2002), 156. Sheffield Trades Historical Society, "A Welcome to Wortley Ironworks," http://www.topforge.co.uk/1955%20Guide.htm. Wortley Top Forge, "History of Iron Making at Wortley," http://www.topforge.co.uk/History%20Notes.htm.

earlier. He said nothing about why he brought them together when he did. He did not refer to any contemporary work that might have prompted it, leaving us with the possibility that his tours of ironworks played a part in his motivation. He was intrigued by the industrial operations he saw on his journeys, and he was prepared to understand them scientifically. They may have stimulated him to complete and draw up a comprehensive theory of heat, and in any event they produced copious examples of it. By bringing together his fundamental researches in chemistry, heat, and mechanics with iron smelting, he would have found a place for industrial Britain in his life of natural philosophy.

An objection might be acknowledged here. The Marxist historian of science James G. Crowther would probably disagree with the suggestion of a connection between Cavendish's journeys and the completion of his mechanical theory of heat. He says that in the second half of the eighteenth century, there arose a new direction in science, one related to industrial society, which emphasized physics, especially heat, and chemistry rather than the astronomy of the solar system, the emphasis in the mercantilist society a century earlier, in Newton's time. Crowther develops this idea in *Scientists in the Industrial Revolution*, a study of Cavendish, Black, Watt, and Priestley, whom he groups with several other men he equally well could have chosen: Boulton, Hutton, Wedgwood, and Erasmus Darwin. Most of them we have encountered as members of the Coffee House Philosophical Society and the Lunar Society of Birmingham. Born in the same decade, 1726–36, they were concentrated in the new industrial districts. The exception was Cavendish, a Londoner, who was exceptional in another way too, owing to his class. Because of his "social outlook" together with his "psychological constitution," Crowther says, he did not hold an "industrial ideology." He together with his associates Banks and Blagden were "attached to the old ruling class," in light of which his interest in industry on his journeys in the 1780s was unexpected. He was curious about Watt's inventions, including Watt's claim of priority in an invention having to do with the steam engine, indicating an appreciation of the inventor's point of view, and he talked with Watt about heat experiments. Crowther doubts that Cavendish brought up his law of energy conservation with Watt, thinking it too abstract to be interesting or to have a bearing on the steam engine. Having derived the law from Newtonian mechanics, the science he was educated in, Cavendish would have regarded it as of only intellectual interest, detached from the industrial sciences of chemistry and heat and from the new technology of power. Cavendish's failure would have come out of the "cultural outlook of the social class to which he belonged," the outlook that prevailed in the Royal Society, Cavendish's principal social connection with science.[88] Cavendish probably did not bring up his derivation of the energy law on his visit to Birmingham as Crowther says, but I doubt that it was because he thought of mechanics as detached from heat. Indeed, it was his interpretation of heat as mechanical energy that separated his and Watt's understandings of the composition of water, the

[88] Crowther, *Scientists of the Industrial Revolution*, 2–3, 321–22. With his approach, Crowther makes some interesting observations about Cavendish, but for the same reason, he can be overly schematic.

core of the water controversy. I think it more likely that he was encouraged by what he observed on his journeys to draw up his theory of heat as mechanical energy, together with the conservation of energy law.

10.5 Journey of 1785

To become acquainted with Cavendish the traveler, we single out one of his journeys, the first, in 1785. In what follows, we depend primarily on the journal for that year and secondarily on letters Blagden wrote before, during, and after the journeys together with a range of published and unpublished works. In the biography of Cavendish I wrote with Christa Jungnickel, I did not fully understand his journeys and their place in his life. In this respect, as in the matter of his personality, this book complements the biography.

Descriptions of industrial processes in the 1785 journal are precise, explanatory, and clear. Technical terms that were used at the site are defined. Quantities refer to a small number of objects: mainly to dimensions of blast furnaces and forges, lengths and times of piston strokes and diameters of pistons, weights of hammers, weights of coke to make a ton pig iron, weights of pig iron to make a ton of refined iron, and times of heating and cooling. Personal names in the diary are few.

The idea of travel almost certainly originated with Blagden. In early 1785, he tried to interest Cavendish in going to Thornhill in Yorkshire to see the progress John Michell had made in the great telescope he was building. Blagden was unsuccessful at first, and by the time Michell extended a formal invitation, he and Cavendish had already set out in another direction.[89] The journey to Wales was Blagden's second plan. He "proposed the scheme one day," he said, of inspecting the ironworks near Cardiff, and when he described them, Cavendish became "very curious" and agreed to make the trip (Fig. 10.3).[90]

They traveled by carriage, but we do not have a description of what kind. Their carriage would not have been a stagecoach, which was unwieldy, uncomfortable, and capable of traveling no more than 3 or 4 miles per hour on good roads. Mail-coaches traveled twice that fast. Among the notes from their journey, there is mention of a "chaise,"[91] which was a lightweight carriage with a folding top, seating two persons side-by-side, having either two or four wheels. If that is what was meant, the travelers would have rented it on their journey for making a side trip, affording them a panoramic view of the land. If a "post-chaise" was meant, it would have been their principal mode of transportation. A post-chaise had four wheels and was drawn by two or four horses, with fresh horses provided at each post along the way.

[89] Charles Blagden to John Michell, 25 April 1785 and 13 September 1785, drafts, Blagden Letterbook, Yale; in McCormmach, *Weighing the World*, 379–82, on 380; 395–400, on 399.

[90] Charles Blagden to William Lewis, 20 June 1785, draft, Blagden Letterbook, Yale.

[91] "Chaise" appears in an untitled document containing barometer and thermometer readings made on the 1785 journey. Cavendish Scientific Manuscripts, Devonshire Collections, Chatsworth.

Fig. 10.3 Map of 1785 Journey. Several places where Cavendish stopped are shown on the map, indicating his itinerary 1. London. 2. Alderley. 3. Cardiff. 4. Merthyr. 5. Colebrook Dale. 6. Birmingham

It accommodated two to four persons, and there could be an accommodation behind for servants. By the standards of the time, it was comfortable, equipped with leaf springs and upholstered seats, and through large front and side windows it too offered a wide view. The post-chaise was popular among travelers in the eighteenth century, and it or the chaise was the typical carriage of families who were respectable but not wealthy. However, because Cavendish owned his own carriage and horses, it seems likely that he would have chosen that means, as it was the usual preference of well-to-do travelers. In a porter's account, his carriage was referred to as a "chariot," a light four-wheeled carriage.[92]

Roads were rough, but improving. Turnpike trusts were set up by which users of roads paid for their maintenance. Every 5 miles or so, roads were blocked by tall white gates. Upon hearing the approach of travelers, turnpike men emerged from little houses beside the gates to take tolls for each vehicle they let pass. Signposts

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[92] Rosamond Bayne-Powell, *Travelers in Eighteenth-Century England* (London: John Murray, 1951), 8–9, 19. Anon., "Georgian Index-Carriages," http://www.georgianindex.net/horse_and_carriage/carriages.html. Anon., "Chaise," http://en.wikipedia.org/wiki/Chaise. History World, "History of Transport and Travel," http://www.historyworld.net/wrldhis/PlainTextHistories. Repair of "chariot" was billed by a coach maker: porter's accounts, March and December 1809, "Bedford Square. James Fuller's Account with the Exec. of Hen: Cavendish Esq. Balance 37.6.4. Settled 30 August 1810."

along roads were rare, but many had milestones.[93] Cavendish and Blagden read milestones and carried maps, and their carriage was probably fitted with Cavendish's way-wiser, or mileage counter.

Except when they stayed with Blagden's relatives, they stayed at inns. Inns were prominent buildings in the towns and villages they passed through. They were easy to see, identified by huge signs with colorful if obscure names such as Bull and Mouth. A wide archway opened onto a yard, which accommodated carriages. The proprietor of an inn, who was a substantial person in the vicinity, would welcome travelers in person. Inns were plentiful; travelers usually had a choice, and they chose inns that were meant for their kind. There was a hierarchy of inns. At the top were posting houses for travelers who arrived in post-chaises or their own carriages. These inns might not accept passengers from mail-coaches, and inns that accepted the latter might not accept passengers from stagecoaches. At the bottom were persons arriving in wagons or on foot, who might not be accepted anywhere, or if they were they might be put up in the kitchen and fed remains.[94] Cavendish and Blagden were welcome at the best inns.

On a recommendation, Cavendish and Blagden might stop at a particular inn where they would be assured an agreeable visit, though it did not always work that way. On their travel to Yorkshire in 1786, they stayed at an inn recommended by their colleague and host John Michell, after which Blagden complained that it was "the vilest house at which I had ever the misfortune to put up."[95] Michell apologized, explaining that the inn was new and he had not stayed there but had heard good reports; he would not repeat the mistake. By and large, English inns were of good quality. Gentlemen who arrived in post-chaises or private carriages were always given private rooms. Rooms were large, clean, and furnished with mahogany furniture and four-post beds heaped with feather mattresses, requiring two steps to mount. Wax candles were provided. The stairs and landings were carpeted, so the traveler would not be disturbed by other lodgers. There was a common dining room, called the "coffee room." Food was usually excellent, distinguished by the quantity and variety of meat, eaten with steel two-pronged forks and knives: mutton, beef, ham, fowl, and fish. There were vegetables, cheese, cakes and pies, and beer and wine. Dinner was followed by tea in the evening.[96]

The historical setting of Cavendish and Blagden's journey into Wales is the Industrial Revolution. Eric Hobsbawm begins his history of the event by calling it the "most fundamental transformation of human life in the history of the world recorded in written documents."[97] It began in Britain with a conjunction of favorable circumstances, which included an expanding supply of labor, capital, and land; participation

[93] Bayne-Powell, *Travelers*, 29–31.

[94] Ibid., 41–42.

[95] Charles Blagden to John Michell, 19 September 1786, draft; in McCormmach, *Weighing the World*, 409–12, on 410.

[96] Bayne-Powell, *Travelers*, 43–47.

[97] Eric Hobsbawm, *Industry and Empire: The Birth of the Industrial Revolution* (New York: The New Press, 1999), xi.

in an international economy; incentives of low interest rates and expectation of high profits; and sources of water, coal, and steam.[98] In the journal of the trip, sources of power and mechanisms for transmitting power to do useful work are recorded, but nothing is said about the social and economic aspects of industrialism. Cavendish's interest in the Industrial Revolution was selective, in keeping with the interest he brought with him on his journeys.

Cotton textiles are synonymous with the early Industrial Revolution,[99] their manufacture having undergone rapid change through a series of technological inventions. Cavendish was not especially attracted to textile sites, however. He was more interested in the mining of ores and the extraction of metals from the ores, subjects with clear connections to his scientific work. The larger part of the journal of 1785 is taken up with descriptions of ironworks.

A Welsh guide book described the production of bar iron. "The impression on the spectator, to whom this scene is novel, is one of extreme interest; he finds himself in the midst of machinery of a peculiar character, and of extraordinary magnitude, remarkable for its massiveness and its weight, and its effect is astonishing."[100] Our spectators were Cavendish and Blagden, and the impression the scene made on them is hard to judge, but in a few places in the journal there is a hint that they were impressed. Because iron production was carried out with intense heat, fiery chemical reactions, and heavy mechanical violence, scenes described in the journal unavoidably appeared Dantesque. Under the hammer, balls of iron removed from the furnace "strike off sparks, some of which fly to a great distance, and a few have the brilliant appearance of steel dust in fireworks. There comes besides a white flame from different parts of the mass, and at times a different flame from certain spots, of a light bluish colour, like that from burning Sulphur."[101] Coalfields in the vicinity of the ironworks suggested an underground inferno. Cavendish and Blagden passed a coal pit that had been burning many years. "From some places close by the road, a strong flame was now issuing, and the earth seen through the crevices and apertures in many places was red hot or even white hot. All about the places actually burning, lay the cinders of old conflagrations."[102]

Blagden's family connections eased their journey. They stayed several nights at each of two locations. The first was Alderly (Alderley), an estate in Gloucester, the birthplace of Matthew Hale, lord chief justice of England at the time of Oliver Cromwell. They were put up there by "Mr Hale," who was John Blagden Hale, Charles Blagden's older brother, who had changed his name only the year before. Having married into the Hale family, John Blagden assumed the name of Hale upon succeeding to the estate of Alderley and the arms of Hale at the death of a member of the family, a later Matthew Hale. The second location was Pentyrch,

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[98] Ibid., 32. T. S. Ashton, *The Industrial Revolution 1760–1830* (Oxford, New York: Oxford University Press, 1996), 17.

[99] Hobsbawm, *Industry and Empire*, 34.

[100] T. E. Clarke, *Guide to Merthyr-Tydfil* (London, 1848), 33.

[101] Cavendish, "Journal 1785," 53.

[102] Ibid., 57.

with "Mr Lewis," who was William Lewis, ironmaster of Pentyrch Ironworks and Blagden's brother-in-law.[103] The month before setting out, Blagden wrote to Lewis about their plans and asked if he and Cavendish could stay with him or if not if he could recommend a place for them to stay in Cardiff. Lewis replied that his house had plenty of rooms, but they were small and low, and his house was close to the hammers. If they wished, they could stay at another house at a distance from the pounding. He promised to show them ores and ironworks.[104]

From the seventeenth century, the prolific Lewis family had played a major role in the rise of iron production in South Wales. William Lewis was an important man in the area. In addition to Pentyrch, his enterprises included iron and coal mines, a warehouse near the Town Quay at Cardiff where he conducted his shipping business, and part interest in Dowlais Ironworks at Merthyr.[105] He owned turnpike gates, farms, and a corn mill. Lewis's letters to his brother-in-law John Blagden Hale give an idea of what it was like to be an ironmaster in South Wales at the time of Cavendish and Blagden's visit. One problem after another required Lewis's attention. Despite his many properties, in the month before Cavendish and Blagden visited him, he wrote to John that he was anxious for the repayment of £200 owned him by a certain party. "I never was so short of Cash as I am," he complained. "During the dry weather we employed our Finers to make Blooms, but very little was drawn out for want of Water, therefore we have a large stock in hand, and the quantity of Charcoal brought in daily is very great w[ch] takes away the Cash." In addition, besides his regular monthly payments, he had several big sums to pay for

[103] Gloucestershire County Council, "Gloucestershire Archives: Online Catalog," http://www.gloucestershire.gov.uk. In the description of the Hale family papers, the catalog guide identifies William Lewis as John Blagden Hale's brother-in-law, and therefore Charles Blagden's brother-in-law. In the correspondence between William Lewis and John Blagden Hale around the time of Cavendish and Blagden's journey, Lewis refers to his wife Mary, presumably Blagden's sister Mary. In the correspondence, Lewis speaks of moving to Alderley. Edgar Chappell writes that in later years Lewis "married a Miss Hale of Alderley and took up his residence at that place." Edgar L. Chappell, *Historic Melingriffith: An Account of Pentyrch Iron Works and Melingriffith Tinplate Works*, 2d ed. (Merton: Merton Priory Press, 1995), 25. The Blagden, Hale, and Lewis families were closely connected by marriage and business.

[104] Blagden to Lewis, 20 June 1785. William Lewis to Charles Blagden, 25 June 1785, Blagden Letters, Royal Society, L.46. William Lewis wrote to Blagden that "we shall with great pleasure receive you & your Friend M[r] Cavendish, in the best manner our small House will admit of." He said the Joy House, previously occupied by Mr. Curtis, was a quieter alternative to his house, and when the river was low only a 3-min drive. In an earlier letter to John Blagden Hale, he referred to the alternative house for Blagden and Cavendish as the Ivy House. 7 June 1785, Gloucestershire County Archives, D1086/F116. Ivy House is thought also to be near the site of another furnace, Tongwynlais Furnace, which had been abandoned by the beginning of the eighteenth century. The house is associated with the Price family, which had close business ties with the Lewis family. It was Nicholas Price father and son and Thomas Lewis who built the Pentyarch Ironworks. We are not told which house Cavendish and Blagden stayed at, but we know they had an obliging host. Philip Riden, "Early Ironworks in the Lower Taff Valley," *Morganwg* 36 (1992): 69–93, on 86; http://welshjournals.llgc.org.uk/browse/viewpage/llgc-id:1169834. Ince, *South Wales Iron Industry*, 145.

[105] Chappell, *Historic Melingriffith*, 23, 26, 38.

cordwood, which he needed for making charcoal. He had a steady order from a buyer of 40 tons of iron a quarter, which he was glad for, but which also troubled him. He thought that the buyer was running his operation at a loss, trading with other people's capital, and that eventually he would fail. He feared he was dealing with an unsound business, and he wanted John's opinion. He considered how to punish a father and his sons who overcharged him, having put ordinary stones and earth in the middle of the heaps of ore in order to be paid for it all as ironstones. He worried about the lease; Billy Price promised them a lease for another year after he came of age. While he was away from Pentyarch, the workers used too much wet charcoal and wet Lancashire ore, which nearly cost him his furnace. One of their partners, he believed, set fire to the rope and all the wood construction in a coal pit, and further threatened to burn it all down. This partner had formerly on two occasions stopped workers from bringing up coal for several weeks, and Lewis thought he should be sued for damages. Winter floods shut down the forges completely for a time, and because of a lack of water to power the furnace, work went very slowly. Lacking workmen, the forges made little iron for a period, and the furnace did not make the usual quantity of iron because the quality of Lancashire ore was poor and the heap of charcoal had gone out. From time to time, Lewis could report good news. He told his brother-in-law that he was about to build an "Air Furnace," a term then used for a reverberatory furnace, employing a flow of heated gases. A month later, he told him that the air furnace was finished, and soon he was melting down old castings and making new ones with it. On Christmas, 1785, he told his brother-in-law that the "Furnace & Forges go on very well," and he had "given the Workers & their Wives plenty of Ale today." In the new year, owing to the death of an owner at Merthyr, he had hopes of buying a coke furnace "cheap."[106] In the midst of his busy life, with its cycle of trials and rewards, Lewis welcomed into his home his brother-in-law Charles Blagden and his friend Cavendish, who had come to be shown how an ironworks works.

The journal of 1785, because of its sparseness and lack of fresh observations of manners and men, makes for dry reading as an account of travels, however informative it may be as technical reportage. As a source of information about Cavendish, however, it is revealing and consistent with what we know about him. We may take it as further evidence of Cavendish's view of the world.

10.6 Synopsis of Journal of 1785

Because the journal was kept as a record for the two travelers only, much was taken for granted that is unfamiliar to readers today. For this reason, I provide a synopsis. It includes information about the journey not given in the journal; it outlines the

[106] William Lewis to John Blagden Hale, 12 March, 7, 22 June, 24 August, 18 October, 25, 31 December 1785; 13, 23 January 1786; 12 January 1787, Gloucestershire County Archives, D1086/116.

industrial setting; and it briefly describes what is new to the travelers at each stop. It also refers to researches Cavendish carried out at home that relate to what he saw on his journeys, pointing to a continuity of interest in new settings.

Day 1. Sunday, July 17. Reading, Crown Inn.[107] Their working day began at 6:30 AM, when they took barometer and thermometer readings up one pair of stairs at the Crown Inn, where they spent their first night. On the road, at 10:23 AM and again at 10:40 AM, they took readings of the same kind on the ground floor of the George & Pelican in Speenham. Through the day, they took readings at inns and stops along the road, a total of nine locations. The last readings were taken on the ground floor of the house in Alderley belonging to Blagden's brother, John Blagden Hale. It was 11 PM; it had been a long day.

Throughout the journey, they took barometer and thermometer readings to determine the heights of places above the sea, and the differences in height between places. They used maps of the region for locations. On their journey to Wales, they recorded their movement through three dimensions.

The barometer and thermometer readings are recorded on sheets separate from the journal, and they are in Blagden's handwriting, so there may have been a division of labor. It was Cavendish in any case who made the extensive calculations for determining heights from the readings.[108] Because with a couple of exceptions they took barometer and thermometer readings every day of their journey, there is no need to bring them up regularly in this synopsis.

Day 2. July 18. Alderlery, Gloucestershire, John Blagden Hale's house. On their journey, at two locations, in Hale's garden on this day and on 25 July at the Pentyrch Ironworks, they determined their true latitude from observations of the sun, using a small Hadley's quadrant and an artificial horizon as a circular spirit level. Cavendish and Blagden both made observations, again on sheets separate from the journal. Cavendish made all the computations, which were considerable, entailing corrections for temperature and time.[109]

Day 3. July 19. Alderley, Hale's house. They observed limestone in the vicinity. Off a turnpike and down a lane, they talked to farmers about blue limestone embedded in local blue clay. They tested coarse-grained limestone with acid. They estimated the angle to the horizon of a stratum of limestone. They passed quarries in which the limestone lay in flat stones. In addition to limestone, they saw blue, red, and white clay, granite, sand, slate, and other rock formations along the way. Here

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[107] The inns where they stayed overnight are not included in the journal for 1785, but they are in a document by Charles Blagden, cited in the next note. On any one day, I give the inn where they started out from.

[108] Charles Blagden, untitled document containing barometer and thermometer readings, journey of 1785. Henry Cavendish, untitled document containing computations of barometric heights, journey of 1785. Both documents are in Henry Cavendish, Scientific Manuscripts, Devonshire Collections, Chatsworth.

[109] Charles Blagden, "Observations with Mr Auberts Small Hadley's Quadrant of 3 Inches Radius by Ramden & an Artificial Horizon as a Circular Spirit Level," ibid. Henry Cavendish, untitled document containing computations of true latitude, ibid.

as elsewhere on the journey, they regularly observed strata, rocks, and pebbles surfacing the road.

Day 4. July 20. Alderley, Hale's house. On this day, they began their visits to industrial sites, which they continued throughout the rest of the journey. They witnessed the process of dyeing cloths in a copper boiler heated by a furnace; the journal gives a detailed account of the boiler, the heat, the chemicals, the procedures, and the handling of cloth. Blagden carried out a small chemical experiment on making dye by dissolving tin in aqua fortis (nitric acid), which he bought. The solution had a yellowish color and the smell of aqua regia (nitric and hydrochloric acid). Early in his career, Cavendish had made a study of the solution of metals and acids, and he had worked out a theory to explain it. The process of dyeing resembled what Cavendish did in his chemical laboratory.

Day 5. July 21. Alderley, Hale's house. They measured the temperature of a spring and of water brought up in a bucket from a deep well. Further along in their journey, in Wales, Cavendish took the temperature of springs while climbing a mountain, and he stopped by a warm spring to test for the kind of air that rose in bubbles,[110] an observation related to his studies of mineral water and of the chemical identity of gases.

Day 6. July 22. Alderley, Hale's house. They visited the Frombridge [Fromebridge] Mill, near Frampton-on-Severn, one of the largest producers of wire in the country.[111] Cavendish and Blagden were shown how wire was made from brass, iron, and steel, the main uses of which were for fishhooks and for teasing and aligning woolen fibers in the cloth trade. Cavendish was interested in wires for their mechanical strength. At home he made experiments on the twisting of wires, and after a meeting with the industrialist Matthew Boulton several years after this journey, he brought back with him a list he had copied out of the weight needed to break wires made of brass, iron, and five other metals.[112] Cavendish and Blagden were shown how brass was made, beginning with melted copper.

Fromebridge also produced pig and bar iron. Cavendish and Blagden saw slitting mills for cutting bars of metal into rods, and they saw flatting, or rolling, mills for producing metal sheets, the mechanical alternative to hammering. All of the mills were powered by water.

At Oakley Wood, they stopped to look at shafts dropping into a tunnel cut for a canal. The shafts, as deep as 35 yards, were vents for circulating air in the Sapperton Canal Tunnel in Gloucestershire. The canal was the Thames and Severn Canal linking the two rivers, intended to supply London with cheap coal from the northern and

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[110] Charles Blagden to Joseph Banks, 9 October 1785, Banks Correspondence, Royal Botanic Gardens, Kew 1.210.

[111] Stephen Mills, "Fromebridge Mill, Frampton-on-Severn, Gloucestershire," *Gloucestershire Society for Industrial Archaeology* (1998): 6–22, on 8–9.

[112] Henry Cavendish, "Weight in pounds required to break wires of metal 1/10 inch diam. Taken from Boulton," Journal of 1793, Cavendish Scientific Manuscripts, Devonshire Collections, Chatsworth, X(a), 2:9. Experiments on twisting of glass tubes and springing of wires, ibid., VI(b), 21. Experiments on twisting of wire tried by the time of vibration, ibid., VI(b), 22.

northwestern collieries. Only about 40 yards of the tunnel had been completed when Cavendish and Blagden saw it, but when it was finished it would stretch 2.2 miles, making it the longest tunnel in the world at the time. This canal did not meet expectations, but generally canals played an essential part in the British Industrial Revolution by providing an economic and reliable means of transportation of materials and products. Cavendish and Blagden's journeys fell in the period known as the "Golden Age" of British canals, 1770s to 1830s. At Oakley Wood, they were interested both in the canal and shafts as engineering works and as an opportunity to study exposed strata.[113]

Day 7. July 23. Gloucester, King's Head. Near Gloucester, where the River Severn divides into two channels, they observed the tide at several locations, timing it and comparing times with local accounts. Cavendish's manuscripts contain a paper about the tides and the earth's motion.

Days 8–10. July 24–26. They arrived at Lewis's house at Pentyrch Ironworks, on the western bank of the River Taff, about 6 miles north of Cardiff. It is where the River cuts through the southern rim of the South Wales Coalfield, and where iron, coal, limestone, and water are found in close proximity. Because of its resources, the region had been home to iron production since Elizabethan times. A furnace and forge were set up at Pentyrch in 1740. On their first day there, Cavendish and Blagden took barometer and thermometer readings in the ironmaster William Lewis's parlor.[114]

Blast furnaces were usually made of stone blocks and lined with firebrick. They narrowed toward the top, and they could be very tall. The furnace at Pentyrch, not one of the tallest, reached 26 ft with a funnel that rose higher. At ground level, blast furnaces were square, holding a hearth with access in the front for tapping the molten iron and slag. Built of stones, the new hearth at Pentyrch was 2 ft on a side and 4 ft deep (Fig. 10.4). Furnaces were built into hills for ease of loading, the ore, fuel, and limestone being alternately introduced from the top.[115] Once going, the red-hot charge reached to the top of a furnace, which might operate continuously for weeks or months. From partway up the furnace, molten iron dripped down through the fuel onto the hearth, where the fusion of the metal took place.

A constant companion of a blast furnace was a means of producing a blast of air, which by increasing the flow of oxygen raised the temperature of the furnace high enough to melt the materials. The blast usually entered the furnace through one or two side openings, or "tuyères." Traditionally the blast was produced by leather bellows operated by cams from a waterwheel. In the second half of the century, in many places bellows were replaced by cast-iron cylinders and pistons, which had greater force. These again were operated by waterwheels, sometimes augmented by

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[113] Candida Lycett Green, "Sapperton Canal Tunnel, Gloucestershire," http://www.candidalycettgreen.co.uk.

[114] Chappell, *Historic Melingriffith*, 23, 26, 38. The book which was originally published in 1940 is updated in an introduction to the second edition by Philip Riden, pp. iii–xii. The starting year at Pentyrch is given by Riden, p. v.

[115] Ince, *South Wales Iron Industry*, 9.

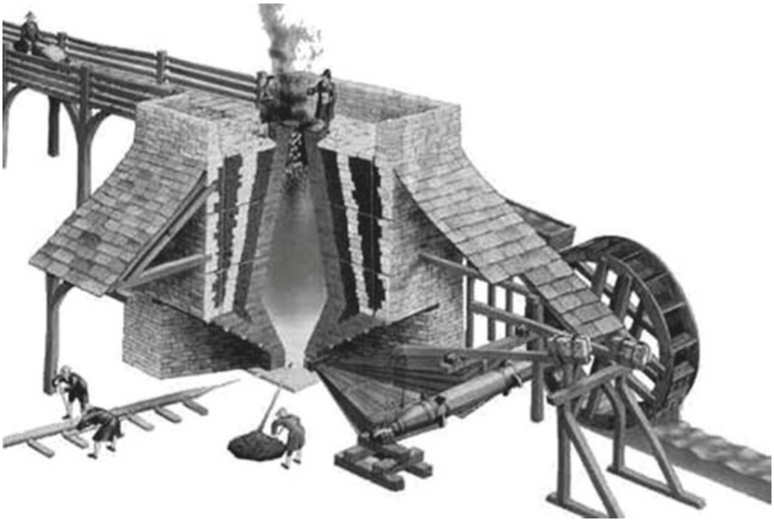

Fig. 10.4 Blast Furnace. The drawing shows a typical blast furnace for smelting iron. At the *bottom* is the hearth, which when tapped releases molten iron. Two ways of collecting it are shown, one a flat sand casting, the other a series of troughs. From the *top*, the furnace is fed iron ore, coal, and flux. A leather bellows powered by waterwheel provides the blast to produce a high temperature (Courtesy of Ironbridge Gorge Museum)

Newcomen steam engines that returned water from the downstream to the upstream side of the wheel. This machinery for producing blast was fairly standard in Welsh ironworks, though occasionally Watt steam engines were used for the purpose.[116]

The River Taff was not navigable, but there was a turnpike route along the valley for transporting iron.[117] From the quay at Cardiff, iron was shipped to Bristol, the commercial center for South Wales iron production. From Bristol William Lewis wrote to his brother-in-law John Blagden Hale that he sent 50 tons of bar iron from the warehouse there by boat for Harford & Co,[118] a typical business operation. Partnerships consisting of merchants from Bristol and other major commercial centers invested heavily in South Wales. To secure their interests they gained control of the sources of supply by engaging in both the production and the selling of iron. If this broader setting of the ironworks was talked about, it did not enter the journal.[119]

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[116] Ibid., 9–11.

[117] The road, following a turnpike act of 1771, instigated by the prominent ironmaster Anthony Bacon, ended at Tongwynlais, 4 miles north of Cardiff. Richard Hayman, *Working Iron in Merthyr Tydfil* (Merthyr Tydfil: Merthyr Tydfil Heritage Trust, n.d.), 8. Riden writes that "there was an easy road journey, improved by turnpiking in 1767, down the valley to the quay in Cardiff." "Introduction," Chappell, *Historic Melingriffith,* iv.

[118] William Lewis to John Blagden Hale, n.d. Gloucestershire County Archives, D1086/F116.

[119] Riden, "Introduction," Chappell, *Historic Melingriffith,* iv, vi.

Cavendish was interested in the smelting processes at blast furnaces and forge furnaces, where raw earth was made to yield its metal. Pentyrch had both kinds of furnaces, but because just then the hearth for the blast furnace was being replaced, he could only see the forges in operation. He was told that when the furnace was working, it used charcoal for fuel, as there was still ample woodland in South Wales for making it.[120] On the day after his and Blagden's arrival, they were shown the forges, one a finery forge and one a chafery. The hearth of the finery was a pit formed of heavy iron plates, with dimensions 2 ft 4 in. in length, 1½ ft in width, and 7 in. deep. The nozzle of a bellows rested on the edge of a side plate of the hearth. "Firework sparks fly off in all parts of the operations in the Finery," the journal records. The chafery hearth differed from the finery chiefly in having no hole in front for the scoria to run off; instead the scoria cohered in masses that were lifted out. The finery used coal as well as charcoal, though the latter worked better. The coal came from Pentyrch mines.

At the finery, a pig of iron was placed on burning charcoal with a blast from a bellows directed at it and workers stirring it constantly. The hot iron lump was removed from the bottom of the hearth with iron pincers, or tongs, and beaten with iron rods to remove scales. Then it was struck with a massive hammer, forcing white hot scoria out of cracks on the surface. The resulting oblong mass or "half-bloom," measuring about 20 in. long and 4 in. thick, was reheated and struck by the hammer again and then beaten into a long bar with knobs at each end, affording a grip for pincers. The iron was moved to the chafery, which was heated by coal, where the knobs were drawn out and the iron was fashioned into utensils. Cavendish and Blagden were shown three kinds of iron, distinguished by color, and having different qualities. Bright gray was the best color, indicating that the iron was made with the right proportion of ore to charcoal in the furnace. The ironworks was set on the bank of the river, but it was powered by water from a tributary, the usual arrangement.[121]

Cavendish and Blagden explored the hills and coal pits around the village of Pentyrch, looking at strata, testing stones with acid, and measuring elevations. The dominant feature of the land there is Garth Mountain, or the Garth, a high, steep ridge formed of sandstone separated by a hollow from another ridge marking the edge of the South Wales Coal Field. Where the River Taff cut through this ridge, it left a hill on its west bank known as the Lower, or Lesser, Garth, a valuable source of iron ore and limestone for ironworks. William Lewis owned an iron-ore mine on the Lower Garth, a big pit on top of the hill. Ore was raised from the pit to the surface and hauled in baskets on the backs of mules and horses along a zigzag path to the Pentyrch Ironworks. Limestone was quarried on the Garth for use as flux in the blast furnace, and coal was mined in levels, slants, and pits on the sides of the Garth and in the valley.[122] On July 26, Cavendish and Blagden climbed to the top of the

[120] Ibid., vi, viii.

[121] Riden, "Ironworks in the Lower Taff Valley," 87.

[122] Chappell, *Historic Mellingriffith*, 38. Riden, "Early Ironworks in the Lower Taff Valley," 69. Anon., "Garth Hill," http://en.wikipedia.org/wiki/Garth_Hill.

Fig. 10.5 Garth Mountain. On the *lower left*, we can see a furnace (Courtesy of Cardiff Central Library)

Garth from Pentyrch carrying their barometer. They may have been dissatisfied or else they wanted a second observation, for they repeated the climb the next day. Cavendish used the two measurements from the second try in calculating the height: He put the top of the Garth at 1,038 and 1,045 ft above sea level.[123] The elevation given on maps today is 1,007 ft (Figs. 10.5, 10.6, and 10.7). After the journey, Blagden wrote to Lewis that their measurements of heights in Glamorganshire were "very coarse, not only because the method with the barometer is not capable of great exactness but also because we had only one."[124]

Day 11. July 27. Pentyrch, Mellengryffyth [Melingriffith] Tinplate Works, or Tin and Iron Works. A forge was established at Melingriffith around 1749, and tinplating was added later. The works was conveniently located 2 miles from Pentyrch along the River Taff, and because Pentyrch smelted hermatite ore, a tough iron

[123] Henry Cavendish, untitled document containing computations of barometric heights, Cavendish Scientific Manuscripts, Devonshire Collections, Chatsworth.

[124] Charles Blagden to William Lewis, 16 February 1790, Blagden Letters, Royal Society 7: 404.

Fig. 10.6 Portable Barometer. (Photograph by the author at Chatsworth). This is probably the barometer that Cavendish took on his journey in 1785 and that he carried to the top of Garth Mountain to measure its height. When folded into its mahogany case, the barometer measures 43½ inches. The instrument is suspended in gimbals. At the bottom, near the wooden cistern, there is a

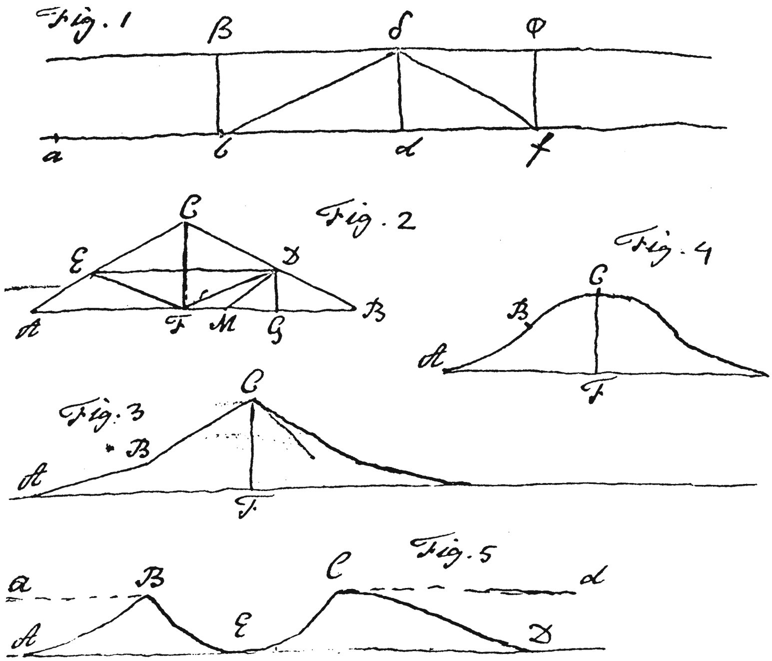

Fig. 10.7 Cavendish's Drawings of Mountains. On his journey of 1785, Cavendish measured the height of mountains. Twelve years earlier, he helped with another measure of mountains, their bulk. This was in connection with an experiment by the Royal Society to measure the gravitational attraction of mountains as a means for determining the average density of the earth. Cavendish drew up rules for selecting an actual mountain for the experiment, and for calculating the attraction of the mountain. He considered a number of shapes of mountains for the purpose ("M^{r} Cavendish's Rules for Computing the Attraction of Mountains on Plumblines," Cavendish Scientific Manuscripts VI (b), 2. Courtesy of the Chatsworth Settlement Trustees)

well-suited for tinplating, the two plants worked together from the beginning. For much of the time they had common ownership. Melingriffith was the first and most important of a number of tin-plating works in South Wales, the center the industry until the end of the Second World War.[125]

Fig. 10.6 (continued) thermometer with a corrections scale. William Roy, with whom Cavendish collaborated on experiments with barometers, used a portable barometer almost identical to this one for taking heights of mountains. Although the Chatsworth barometer is unsigned, we know from Roy that this kind of barometer was made by Jessie Ramsden. It was highly accurate. The height of the mercury column was read to one-five hundredths part of an inch by means of a nonius moved by rack work. Roy used two such instruments in his experiments, finding them to agree within a few thousandths of an inch (Roy, "Experiments and Observations Made in Britain, in Order to Obtain a Rule for Measuring Heights with a Barometer," *Philosophical Transactions* 67[1777]: 653–787, facing 658. The photograph is reproduced by permission of the Chatsworth Settlement Trustees)

[125] Riden, "Introduction," in Chappell, *Historic Melingriffith,* iv–v.

Pig iron produced by Pentyrch was sent to the Melingriffith finery and chafery forges. Wrought iron from the forges was flattened into sheets at one of the two rolling mills. Cavendish and Blagden's journal described in detail the rather complicated process of preparing the sheets for coating with tin. The source of power at Mellingriffith was water diverted from the River Taff into an artificial channel, which also served as a canal bringing raw iron from the Pentyrch Ironworks.[126]

Day 12. July 28. Having heard about blue lyas limestone at Penarth Point, Cavendish and Blagden spent the day there looking at strata.

Days 13–14. July 29–30. Pentyrch and Merthyr. In his correspondence with Charles Blagden, William Lewis said he would show them the ironworks at Merthyr too. In the 25 years between 1759 and 1784, four ironworks were built near one another on the outskirts of Wales's first industrial town, Merthyr or Merthyr Tydfil: Dowlais, Plymouth, Cyfarthfa, and Penydarren. Copper and tinplate were important industries in South Wales, but iron was king, and the Merthyr-Tydfil ironworks were the heart of the iron industry there. The Merthyr works were still modest in size when Cavendish and Blagden saw them. In 1784 they had only 4 blast furnaces between them, but in 1812 they had 18, and in 1850, at their height, 41. Merthyr was the center of the British iron trade in the nineteenth century, and for a short time two of the ironworks, Cyfarthfa and Dowlais, were the largest in the world (Figs. 10.8, 10.9, 10.10, and 10.11).[127]

In the morning, Cavendish and Blagden inspected a new furnace at "Merthyr." Their description indicates that they probably visited Penydarren Ironworks, the latest and final ironworks in the vicinity of Merthyr. In the journal, Cavendish wrote of a furnace "just erected" by "Messrs Humphries." Penydarren Ironworks was begun in 1784, the year before Cavendish and Blagden's visit, by the Homfray brothers, Samuel, Jeremiah, and Thomas, and the first blast of the furnace was in 1785. On their visit to this ironworks, Cavendish and Blagden spoke with "the Engineer, whose Name is Birch." He would have been James Birch, engineering partner and manager of Penydarren until 1801.[128] The new furnace burned coke, the first mention of this fuel in the journal, though it was not the first coke-fired furnace of the Merthyr group of ironworks.[129] The coke was made on the spot, from local coal, and it was made in an open pile rather than in a covered oven, a method common in the second half of the eighteenth century. The use of coke in furnaces made South Wales, with its abundant carbon-rich coal, attractive to the iron industry, though coke supplemented rather than replaced charcoal.

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[126] Friends of Melingriffith Water Pump, "Melingriffith Tin Works," http://friendsofmelingriffith-waterpump.org.

[127] Lewis was part owner of Dowlais. Hayman, *Working Iron in Merthyr Tydfil*, 3, 8–10. John A. Owen, "Merthyr Tydfil – Iron Metropolis 1790–1860," published in the series *Merthyr Historian* 1 (1976): http://himedo.net/TheHopkinThomasProject/TimeLine/Wales/MerthyrTydfil/OwenMerthyrTydfil.

[128] Ince, *South Wales Iron Industry*, 36, 57, 80. Anon., "Samuel Homfray," http://en.wikipedia.org/w/index.php?title=Samuel_Homfray&oldid=513293991. If by "Merthyr" Cavendish and Blagden did not mean Penydarren, the ironworks would likely have been Dowlais, of which William Lewis was part owner.

[129] The first was Cyfarthfa.

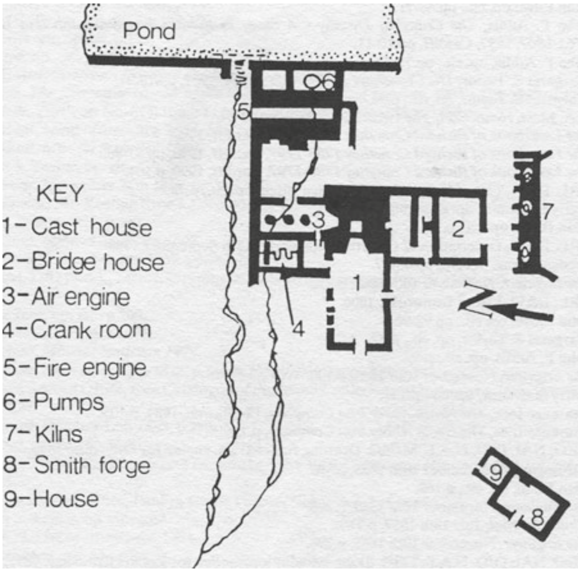


Fig. 10.8 Plan of Early Ironworks. Dowlais furnace 1763. Dowlais Ironworks was founded in 1759, the first of the four Merthyr Ironworks. The so-called "Merthir Furnace" was the first modern furnace in the area. Compared with later ironworks at Merthyr, the one shown on the plan is small, about 150 ft across; its largest building "cast house" is about 35 by 85 ft, not much larger than a large cottage (Bruce Thomas, "Merthyr Tydfil and Early Ironworks in South Wales," in *The Company Town: Architecture and Society in the Early Industrial Age*, ed. J. S. Garner [Oxford, New York, Toronto: Oxford University Press, 1992], 20–21. Ince, *South Wales Iron Industry*, 1, 68)

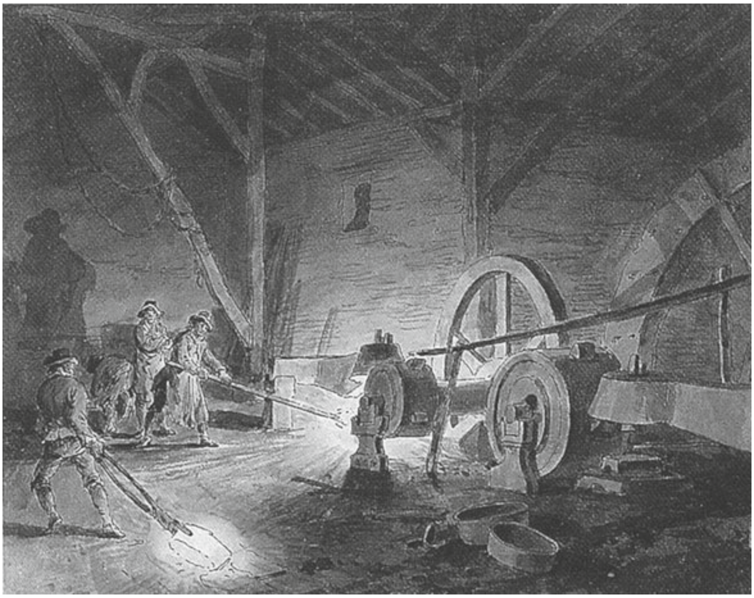


Fig. 10.9 Working Iron at Merthyr Tydfil. Watercolor by J. C. Ibbetson in 1792. A mass of hot iron is being struck by a trip hammer to remove slag (Courtesy of Cyfarthfa Castle Museum)

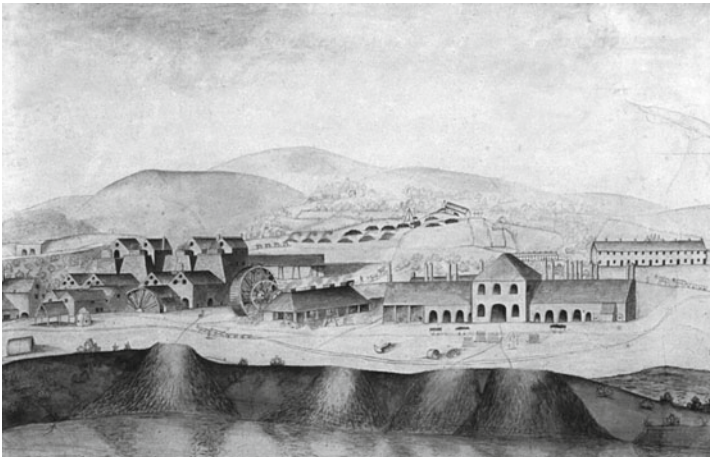


Fig. 10.10 Cyfarthfa Works and Waterwheel. Drawing by William Pamplin between 1791 and 1800. In the *center* we see a wonder of the early Industrial Revolution, an overshot waterwheel 50 ft across and 6 ft wide, made of cast iron, weighing approximately 100 British tons, reputed to be the largest in the world at the time. It was named Eolus after the Greek god of the winds. Water to turn it was conveyed from the surrounding hills by a raised stone double aqueduct. On each side of the waterwheel was a secondary wheel which operated the bellows that supplied blasts at Cyfarthfa's four furnaces and four fineries. Behind the Ironworks, we see coals being burnt to produce charcoal for use in the furnaces. (Thomas, "Merthyr Tydfil," 20. Courtesy of Cyfarthfa Castle Museum)

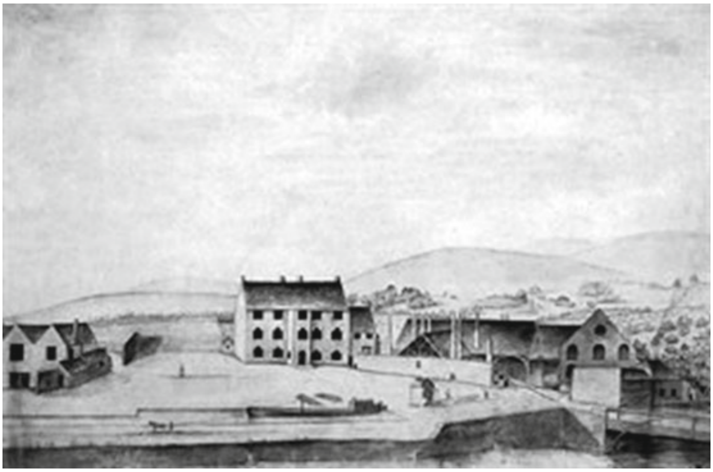


Fig. 10.11 Cyfarthfa House and Works. Drawing by William Pamplin between 1791 and 1800. The house of the ironmaster is next to the works. In the foreground we see the head of the Glamorganshire Canal. In 1790, the ironmasters of the four autonomous Ironworks around Merthyr agreed to build a canal. Until then, transport of materials between Merthyr and the port of Cardiff was by mountain road and pack animal, slow and expensive. The canal, which was completed in 1794, was 25 miles long, laid along the west bank of the River Taff. The drop was over 500 ft, requiring 51 locks. The canal was an immediate success. A barge could travel from Merthr to Cardiff in 20 h. More than any other project, it was responsible for the large-scale industrial development of Merthyr. (Thomas, "Merthyr Tydefil," 22. Courtesy of Cyfarthfa Castle Museum)

Because coke was harder to burn than charcoal, wherever coke replaced charcoal in blast furnaces a powerful blast was needed. The blowing cylinder of the coke blast furnace at Merthyr was 6 ft across and powered by “a fire engine on the old construction.” “Fire engine” meant steam engine in the eighteenth century, and the reference to “old construction” would have been to a Newcomen steam engine, the first appearance of a steam engine in the journal. In this case, the blowing cylinder was operated directly by a steam engine rather than indirectly through a waterwheel.

The new furnace at Merthyr rose 60 ft. Tall as it was, Cavendish and Blagden could see a strong flame issuing from the top. The proportion of width to height of this furnace differed from that of the one at Pentyrch, the Penydarren furnace being higher and narrower making for a better draft and hotter fire. The castings from the iron produced by the Merthyr furnace on Cavendish and Blagden’s visit were mainly iron plates used for copper plating. The ore for smelting came entirely from local hills.

They next visited Cyfarthfa Forges, about 1 mile from Penydarren.[130] Charcoal finery forges had low output. To increase it, a process known as “stamping and potting” was introduced in the 1760s, one of a number of inventions that made use of coal or coke rather than charcoal. At Cyfarthfa Ironworks, a relative of one of the owners was employed to build a forge for potting and stamping, for which he and his brother had a patent. In potting and stamping, pig iron from a coke blast furnace was first melted and stirred in the forge until it became a lump, as in the charcoal process only using coal or coke as fuel. The lump was hammered into plates, which were broken up, or stamped, with hammers. The pieces together with the small bits of iron broken off were placed in uncovered cylindrical clay pots, insulating the iron from impurities in the coal. The small bits served as flux, which assisted in welding the plates together, and they also entered into the composition of the iron. The pots were heated but not so much that the iron melted. This process produced the bloom, which was laid under the hammer again. Water from the River Taff powered the blast at this forge, as it did at the chafery forge. It also powered the hammers, stampers, and a clay mill for making pots used in stamping and potting.[131] Two years after Cavendish and Blagden’s visit, Cyfarthfa adopted the superior Cort puddling process for making wrought iron, one of the first ironworks to do so.

They looked only at the forges. The journal does not mention the furnace for making pig iron or the boring mill for making cannon. Like many ironworks, Cyfarthfa had secured good contracts with the Board of Ordnance for cannon during

[130] The journal mentions that Mr. Bacon leased the forges to Mr. Tauper. The second name is unfamiliar. Anthony Bacon and William Brownrigg started Cyfarthfa Ironworks in 1765. In 1771 Brownrigg retired, and in 1782 Bacon leased part of the ironworks, which included a forge, to Francis Homfray, who held it for 2 years. In 1784, it passed to David Tanner, who was owner when Cavendish and Blagden visited.

[131] Anon., “Cyfarthfa Ironworks,” http://en.wikipedia.org/wiki/Cyfarthfa_Ironworks. Anon., “Potting and Stamping,” http://en.wikipedia.org/wiki/Potting_and_stamping. Hayman, “Shropshire Wrought-Iron Industry,” 79.

the recent American War of Independence.[132] As before, Cavendish and Blagden studied the strata of the hills around the ironworks.

Day 15. July 31. Brecknock, Golden Lion. They traveled this day, noting lime kilns on the way, and gathering a bounty of heights as measured by the barometer. From Monmouth, Blagden sent Banks a positive report of their journey so far. They had seen cloth and iron manufactures in "great perfection," and in measuring the highest mountains in four counties, they had been "perfectly successful." They were going to Birmingham, with plans to measure the Malvern Hills.[133]

Day 16. August 1. Monmouth, Beaufort Arms. They had left Wales and were back in England, still on the road.

Days 17–18. August 2–3. Worcester, Hop-Pole. Birmingham, Swan Inn. At Birmingham, they visited Matthew Boulton's Soho Manufactory. Birmingham had long been a center of the ironworking industry, and when Cavendish and Blagden arrived it was also a center of the steam-engine business. Steam belonged to a branch of natural philosophy on which Cavendish was an expert, heat. Several years before his journey, he had made a thorough experimental investigation of the elastic force of steam, which he carefully wrote out but did not publish. The editor of his papers supposed that Cavendish took up the subject both for its scientific interest and for its connection with the steam engine, then growing in importance and in need of good empirical data.[134]

The inefficiency and other deficiencies of the early Newcomen steam engine were answered by Watt, who patented an improved steam engine incorporating a separate chamber for condensing steam at the end of a cycle. Watt entered into partnership with the Birmingham businessman Boulton to market the engines, and in 1776 they installed two engines, one at a colliery and one at Wilkinson's ironworks at New Willey, mentioned above. The engines were soon in demand, and Watt continued to improve them (Figs. 10.12, 10.13, 10.14, 10.15, 10.16, 10.17, 10.18, 10.19, 10.20, 10.21, 10.22, 10.23, 10.24, 10.25, 10.26, 10.27, 10.28, 10.29, and 10.30).

Cavendish and Blagden's journey coincided with a turning point in the development of steam power. In the early 1780s Watt patented three major improvements. The first translated the reciprocal motion of the steam engine into a rotary motion, useful in manufacturing of many kinds. Watt's machinery for accomplishing this is known as a "sun-and-planet gear." Cavendish described the gear and also the alternative, a crank and wheel patented in 1780 by one of Watt's former employees. The second improvement was the "double-acting" rotative steam engine, which enabled the same engine to deliver twice the amount of power. The third was an application of the pantograph principle to give the piston the motion it needed for a double-acting engine. The journal contains Cavendish's drawing of the pantograph,

[132] Ince, *South Wales Iron Industry*, 60–61. Hayman, *Working Iron in Merthyr Tydfil,* 8. John Lloyd, *The Early History of the Old South Wales Ironworks 1760 to 1840* (London: Bedford Press 1906), 51, 93–94.

[133] Charles Blagden to Joseph Banks, 31 July 1785, Banks Correspondence, Royal Botanic Gardens, Kew 1.199.

[134] Henry Cavendish, "Tension of Aqueous Vapour," *Scientific Papers* 2: 362–72.

Industrial Tourist

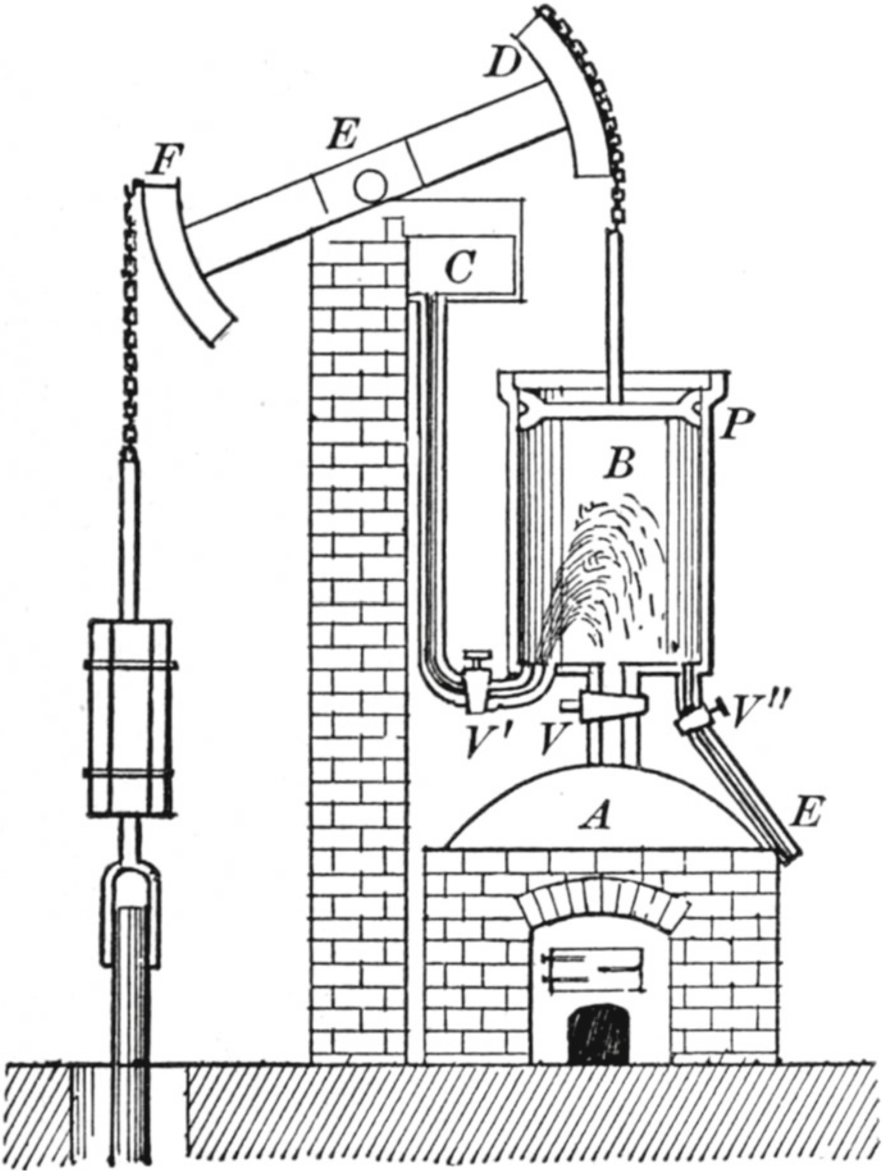


Fig. 10.12 Newcomen Steam Engine. Also called the "atmospheric engine", the Newcomen was the first steam engine that could raise water from deep mines. It was invented by Thomas Newcomen in 1712, and through the eighteenth century it was installed at British mines. It was also used to lift water to drive waterwheels at ironworks. In the diagram, the pump is on the *left* outside the engine house. FED is a rocking arm. Steam from the boiler enters the cylinder lifting the piston. Cold water from the water tank C is injected into the cylinder condensing the steam and creating a vacuum. Atmospheric pressure drives the piston down, rocking the beam and working the pump (Wikimedia Commons)

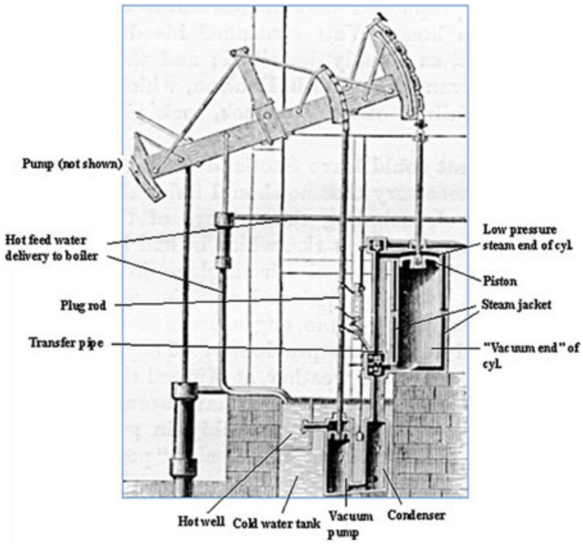


Fig. 10.13 Watt's Steam Engine. This was an improved version of the Newcomen steam engine. The latter made inefficient use of steam. By alternately injecting steam and cold water into the cylinder, the cylinder walls were heated and cooled with each stroke; when steam was introduced, it continues condensing until the cylinder walls were heated again, wasting heat. Watt's new idea was to add a separate condensation chamber; coldwater was injected only into it, the working cylinder remaining hot. As in the Newcomen engine, the Watt engine in the diagram does work only on the downward stroke of the piston. The weight of the pump, the counterpoise on the beam, raises the piston, and steam flows into the cylinder under the piston. On the downward stroke, the steam is drawn by vacuum into the condensation chamber, whereupon condensing, it maintains the vacuum. The vacuum is created by an air pump. The condensation chamber is submerged in a cold water bath (Wikimedia Commons)

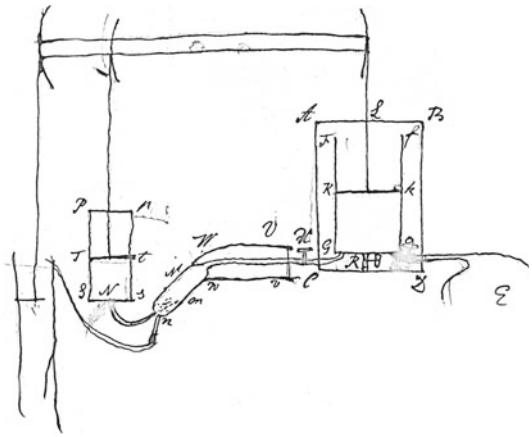


Fig. 10.14 Cavendish's Drawing of a Steam Engine. In this diagram, *Mm* is the condensation chamber, *Pp* is the air pump, and is *Ff* is the working cylinder. Cavendish gives the dimensions and the strokes per minute of the engine he describes, and he notes its advantage: "In common engine [Newcomen engine] as much steam condensed on sides as is used to fill the cylinder." (Cavendish Scientific Manuscripts, Devonshire Collections, Misc. Reproduced by permission of the Chatsworth Settlement Trustees)

Fig. 10.15 Old Bess Steam Engine. An early beam steam engine built by Boulton and Watt, 1777. Preserved in the Science Museum, London (Wikimedia Commons)

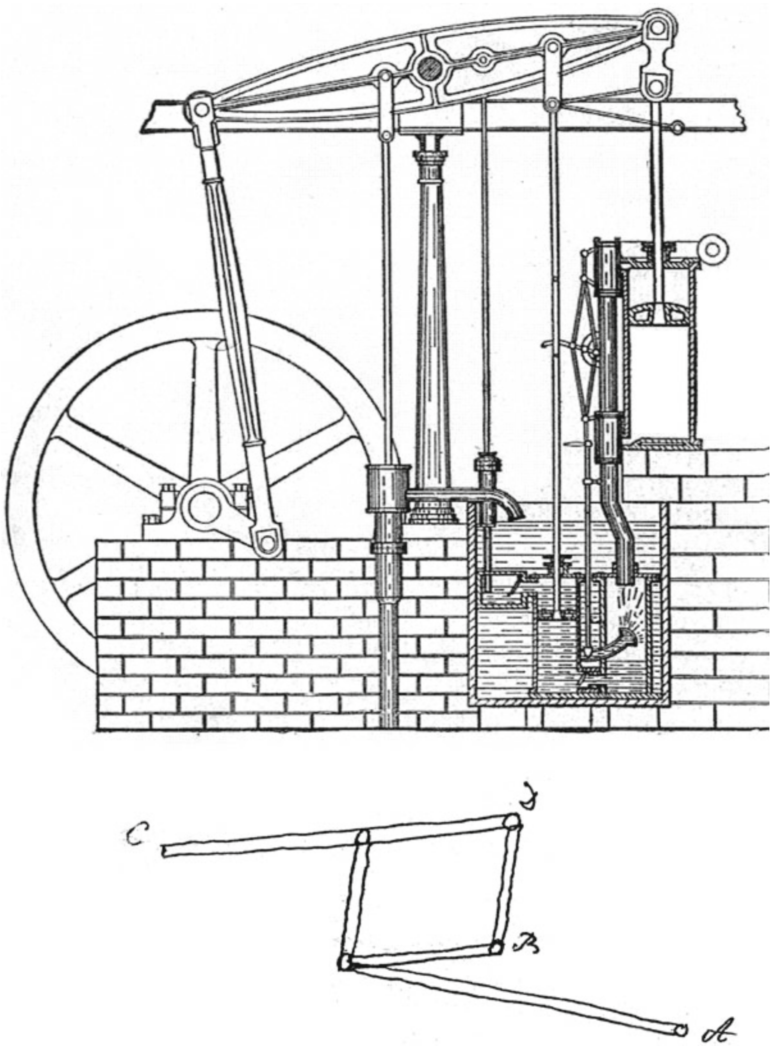


Fig. 10.16 Parallel Motion. In the early Watt engines, the piston was connected to the beam by a chain. By replacing the chain with a rod, it was possible to develop power on the upward as well as downward stroke, to push as well as pull, doubling the action of the engine. There was a problem, however. The piston rod moved vertically, while the beam moved circularly. Watt solved the problem with a four bar linkage between the rod and the beam. This took the form of a familiar pantograph, which produces parallel lines; in this case, parallel motion. A piston moving vertically up and down transmitted force in both directions to a circularly moving beam. Watt took out a patent on his "parallel motion" in 1784. The device on the steam engine is seen on the *upper right*. Cavendish drew a picture of the linkage in his 1785 journal; it is shown at the *bottom* of this illustration (Wikimedia Commons)

Fig. 10.17 Sun and Planet Gear. The gear is shown on a Boulton and Watt engine of 1788. There was a related problem to parallel motion, the translation of the motion of the beam to the turning of a wheel. This can be done simply by a crank, but there was already a patent; a Watt engine with a crank is shown in the previous illustration. To solve the problem, Watt adapted an idea proposed by one of his employees an epicyclic sun and planet gear. It involves two cogwheels. One is fixed to a rod descending from one end of the beam, the other is attached to the axle of the wheel to be turned. Watt patented the gear in 1781. Cavendish and Blagden referred to it in their journal (Wikimedia Commons)

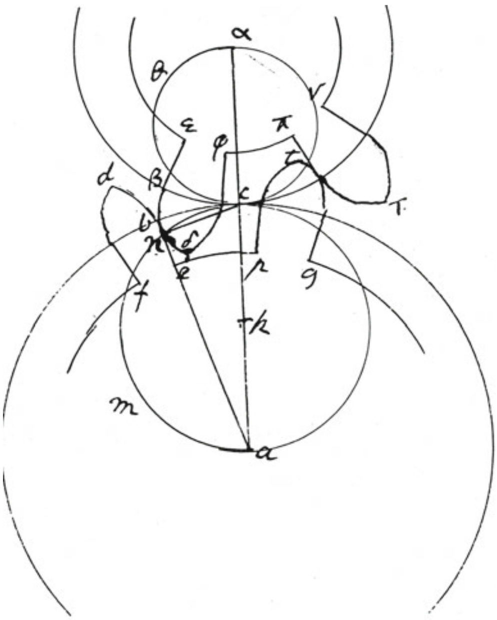


Fig. 10.18 Cavendish's Drawing of Rackwork. In their journal of 1785, Cavendish and Blagden described actions of machinery, including gears, or rackwork. For his course of lectures on natural philosophy at the Royal Institution, Thomas Young asked Cavendish's help with a problem of the teeth of gear wheels. The drawing here was part of Cavendish's response. (Cavendish Scientific Manuscripts VI (b), 31. Reproduced by permission of the Chatsworth Settlement Trustees)

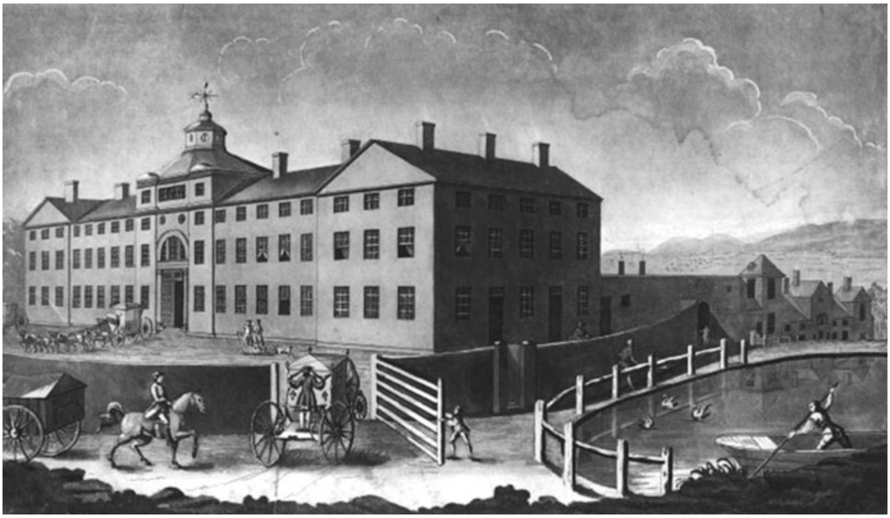
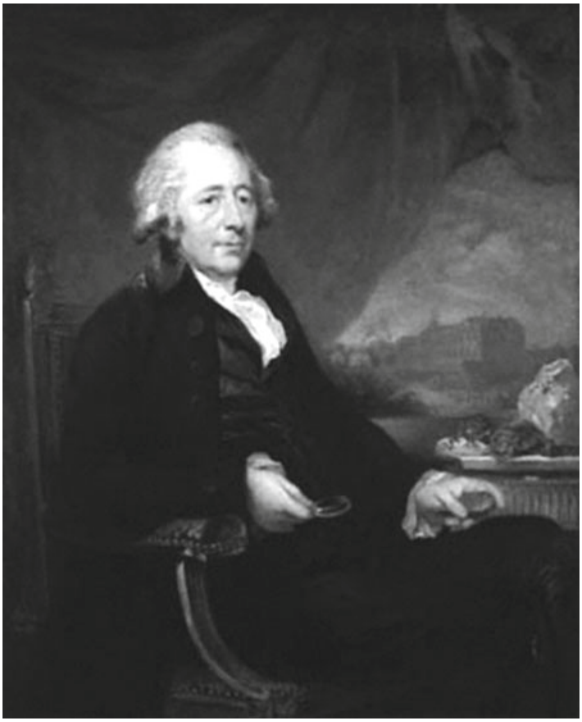


Fig. 10.19 Soho Manufactory. Aquatint over etching by Francis Eginton in 1773. Near Birmingham. Founded by Matthew Boulton and John Fothergill, and completed in 1766, the factory had a Palladian front, bays for loading and unloading, and quarters for clerks and managers. Other buildings contained workshops with advanced metalworking equipment. The industrial complex was much admired and frequently visited (Wikimedia Commons)

Fig. 10.20 Matthew Boulton. By Carl Frederick von Breda in 1792. Manufacturer and business partner of James Watt. Boulton & Watt steam engines were installed by the hundreds in the late eighteenth century (Wikimedia Commons)



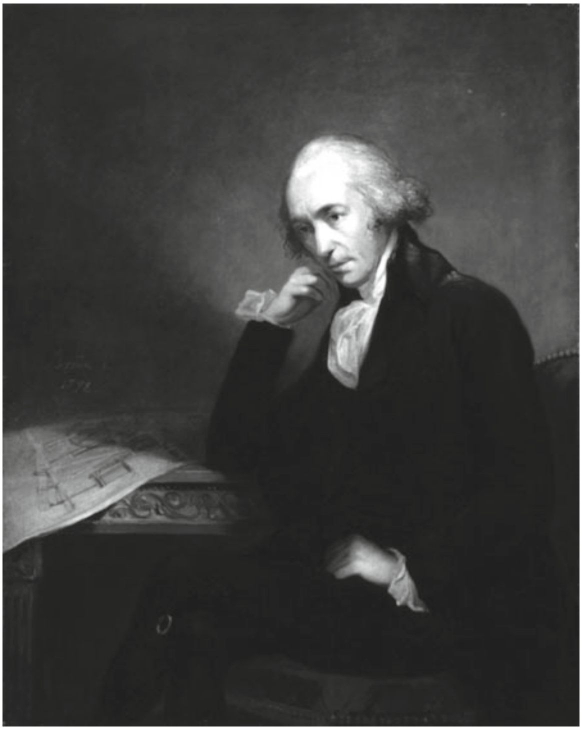


Fig. 10.21 James Watt. By Carl Frederick von Breda in 1792. Engineer and inventor. Best known for his improvement of the Newcomen steam engine (Wikipedia Commons)

Fig. 10.22 John Wilkinson. By Lemuel Francis Abott. Ironmaster and inventor (Wikimedia Commons)

Fig. 10.23 Smelting House at Broseley. Engraving by Wilson Lowry, after George Robertson, 1788. In 1757, John Wilkinson with partners erected a blast furnace at Willey, near Broseley in Shropshire. He later built another ironworks at New Willey, which Cavendish visited. In this picture, we see molten iron flowing from the furnace into a sand pig bed (Courtesy of the Ironbridge Gorge Museum Trust)

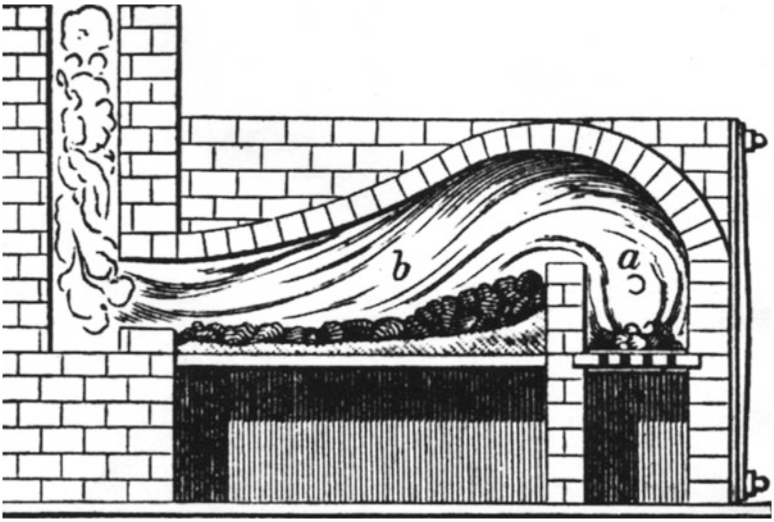


Fig. 10.24 Reverberatory Furnace. The fire is at *a*, the iron at *b*. (http://www.probertencylopaedia.co/photolib/misc)

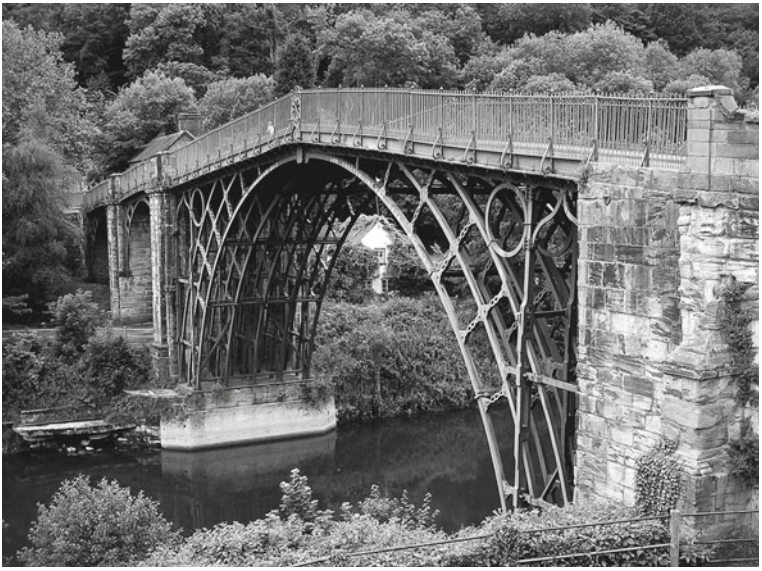


Fig. 10.25 Ironbridge. "The Cast Iron Bridge near Coalbrookdale," oil painting by William Williams about 1780. Opened in 1781, the 100-ft Iron Bridge spans the River Severn in Shropshire. John Wilkinson was instrumental in initiating the construction of the first bridge to be made of cast-iron. Abraham Darby III's ironworks in Coalbrookdale produced cast-iron at a reasonable cost, making a bridge feasible. The bridge is another wonder of the early Industrial Revolution (Courtesy of Ironbridge Gorge Museum)

Fig. 10.26 An Iron Work for Casting Cannon. Engraving in 1788 by Wilson Lowry, after George Robertson. Shown is Alexander Brody's cannon foundry on the south bank of the River Severn, a half-mile downstream from the Iron Bridge. Cannon-making was big business in the Gorge (Courtesy of the Ironbridge Gorge Museum)

Fig. 10.27 Upper Works at Coalbrookdale. Hand-colored engraving in 1758 by François Vivares, after Thomas Smith of Derby. In the foreground, a wagon drawn by horses transports a cast-iron cylinder for a Newcomen steam engine. Piles of coke can be seen on the far *right* and the square top of a furnace in the *center*. Houses belonging to the succession of Darby ironmasters can be seen on the hill (Courtesy of the Ironbridge Gorge Museum)

Fig. 10.28 Coalbrookdale by Night. Oil painting in 1801 by Philip James de Loutherbourg. The source of the fiery glow is molten iron tapped from the Madeley Wood, or Bedlam, Furnaces on the right. The large building on the *left* is Bedlam Hall, which has nothing to do with furnaces. In the foreground, we see horses pulling a wagon on a plateway alongside some large castings. From 1776 to 1796, the furnaces belonged to Darby's Coalbrookdale Company. Built in the 1750s, they were probably where iron was cast for the Iron Bridge, a half-mile upstream (Courtesy of the Ironbridge Gorge Museum)

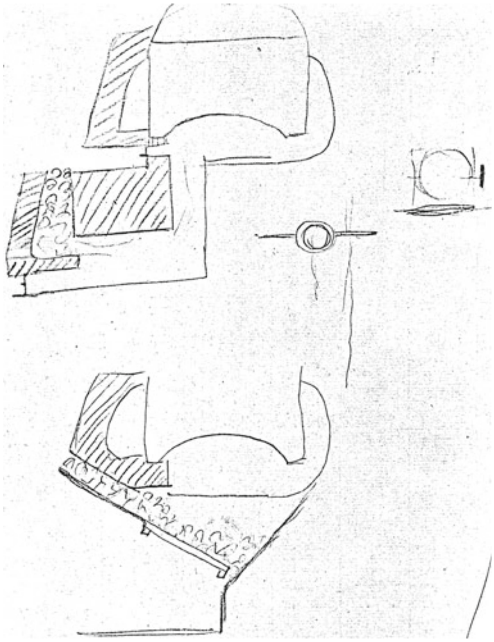


Fig. 10.29 Cavendish's Drawing of Watt's Furnace for Burning Smoke. In 1785, Watt patented a smoke-consuming furnace, which had two sources of heat. On a grate, there was a regular fire. Where the fire was drawn into a flue or chimney, there was a second grate containing red-hot coals that had ceased to smoke, and there the smoke of the first fire was consumed (Cavendish Scientific Manuscripts, Devonshire Collections, Chatsworth, Miscellaneous)

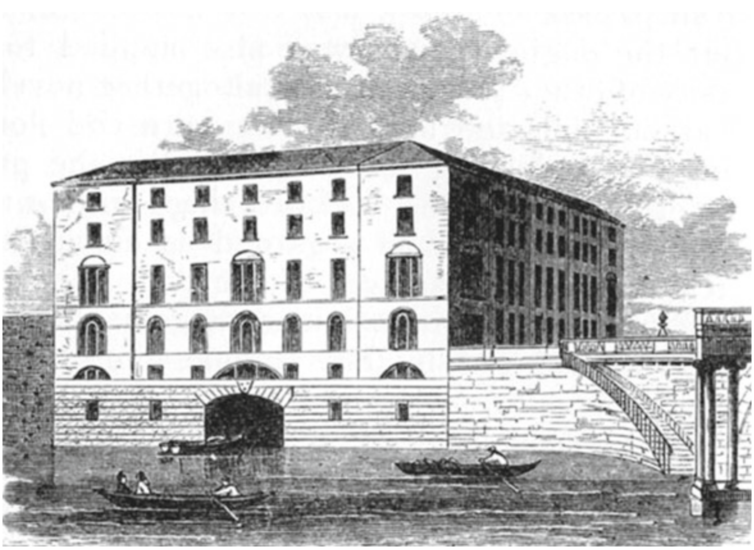


Fig. 10.30 Albion Mills. Cavendish may have drawn Watts smoke-consuming furnace in Birmingham on his journey in the summer of 1785, or he may have observed it at Albion Mills, located on the Surrey side of Blackfriars Bridge. Built-in 1783–86, Albion Mills was the largest and technologically most up-to-date flour mill of the time (Wikimedia Commons)

considered by Watt his masterwork. Watt's double-acting steam engine would be the standard engine to the end of the century.

Industry in Britain had developed without much assistance from science, but that would change. Cavendish foreshadowed the change on his visit to Watt, who had improved the steam engine through a combination of inventiveness and applied science. Cavendish and Watt both studied heat experimentally, and at their meeting in Birmingham Watt described his experiments to Cavendish.[135] If we follow Wilson in calling on the ancient concept of microcosm and macrocosm, we see in Watt's experiments and Cavendish's preoccupation with science and his fascination with technology a foreshadowing of the dynamic society set in motion by the Scientific and Industrial Revolutions.

Day 19. August 4. Near Broseley in Shropshire, New Willey Ironworks. New Willey was the logical next stop, its ironmaster Wilkinson having aided Watt materially in his improvement of the steam engine. His boring mill for making cannon turned out to be exactly what Watt needed to make accurate cylinders for his engines, correcting their inefficiency through leakage of steam.[136] Powered directly by a Watt steam engine, the cylinder and piston machine for producing the blast for New Willey's two furnaces was similar to what they had seen at Penydarren. A second steam engine lifted water to power the hammers. The finery used coke instead of charcoal, and the method was basically the same as the one at Cyfarthfa, stamping and potting. The resulting wrought iron was rather brittle, but good enough for nails, the main product of the New Willey finery forge. Wilkinson blamed the brittleness not on the coke but on the nature of the ore. All of the iron produced at New Willey was made with coke, which was got from local coal. The iron ore too was local. Cavendish and Blagden discussed ores and local strata with Wilkinson (Figs. 10.22 and 10.23).

Day 20. August 5. Coalbrooke Dale [Coalbrookdale], Rathbone's Works; Broseley, New Willey Ironworks. In 1709, Abraham Darby rebuilt a blast furnace at Coalbrookdale, made notable for its use of coke instead of charcoal as fuel; that year he started Coalbrookdale Company, destined to prosper as a family venture. His pots and other products were all made of cast iron. In 1778 Abraham Darby III, third-generation head of the company, made castings for Iron Bridge (Ironbridge), the first cast-iron bridge in the world and the first major structural use of cast iron. The still-standing 100-ft, semi-circular bridge spanned the River Severn, linking ironworks at Coalbrookdale with industrial sites across the river.[137] It happened that two Rathbones of Liverpool

[135] In 1793, Cavendish took another journey, this time without Blagden, initiated by the president of the Royal Society, Banks. A new steam engine had been installed at the Gregory lead mine in Derbyshire, in which both the Banks family and the Cavendish family had interests. Banks wanted Cavendish to meet him there to view it, and he wanted Watt or Boulton to join them. The notes Cavendish kept of the journey describe an experiment Watt made with a steam engine to determine the density of steam. Henry Cavendish, Journal of 1793. Joseph Banks to Matthew Boulton, 6 and 18 July, 10 August 1793, Birmingham Assay Office.

[136] Schubert, "Extraction and Production of Metals," 103–4.

[137] S. B. Hamilton, "Building and Civil Engineering Construction," *History of Technology*, vol. 4: *The Industrial Revolution, c1750 to c1850*, ed. C. Singer, E. J. Holmyard, A. R. Hall, and T. I. William (New York and London: Oxford University Press, 1958), 442–519, on 455–56.

married into the Darby family; Cavendish and Blagden called the ironworks they visited Rathbone's Works (Figs. 10.24, 10.25, 10.26, and 10.27).[138]

The plant was large, a quarter mile in length. The blast for its two furnaces was delivered by two cylinders powered by water raised by a steam engine of Watt's design. The year of Cavendish and Blagden's visit a steam engine was installed to blow air at two fineries located outside the building.[139] There was the expected mill for boring cylinders. In a plant belonging to the same company, they saw tar being made from coal.

For lack of water for power, the operation of shingling had been abandoned at Coalbrookdale, and Cavendish and Blagden returned to the New Willey Ironworks to observe it there. The operation differed from what they had seen principally in the use of a reverberatory ("wind") furnace (Fig. 10.28). In this type of furnace, the iron did not touch the contaminating fuel as it did in a blast furnace or in a finery but was heated by hot gases that flowed over it and also by the radiant heat reflected from the roof of the furnace; "reverberatory" refers to reflection. The initial steps were ones we have seen before in stamping and potting. The pig iron was heated in a coke finery to turn it into tough iron, which was then stamped and broken into pieces, and they together with small bits knocked off by the stamping were placed in cylindrical clay pots. The pots were then set in a reverberatory furnace fueled by coal and left there until the iron was at its melting point but still solid. Under the intense heat, the pots cracked, scoria flowed out, and the iron retained the cylindrical form of the pots, called "balls." The balls were dragged by pincers to a large forge hammer and beaten. Finally the iron, now oblong in shape, was drawn out into bars in the chafery forge.

Day 21. August 6. Birmingham, Swan Inn. Returning to Birmingham, they turned off the road at Bradley Furnace and Forges, a new ironworks built by Wilkinson. A steam engine of Watt's construction powered the blast at the furnace. Nothing there was cast directly. Instead all iron pigs from the furnace were carried to a foundry, equipped with reverberatory furnaces and the machinery of cranes. Blooms from the forge hearths were hammered to give them the proper thickness and then they were cut in lengths. These were passed through a rolling mill several times, producing long bars, which were then sent to a slitting mill, producing rods from which nails were made. A steam engine turned two wheels on separate axes, each wheel turning a rolling and a slitting mill.

Cavendish and Blagden learned that Watt had invented a furnace to burn smoke, which he intended to apply to the steam engine. Cavendish drew a sketch of it. In

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[138] Joseph Rathbone married Mary Darby, daughter of Abraham Darby II, and the year after Cavendish and Blagden's visit William Rathbone married Hannah Mary Darby. Relatives of the founder owned most of the shares, some of which were mortgaged to William and Joseph Rathbone, who were large investors. Alan Birch, *The Economic History of the British Iron and Steel Industry, 1784–1879* (1967; reprinted Abingdon, Oxon: Routledge, 2006), 62. The name "Rathbone's Works" may have been an alternative: in 1781 a pumping engine "was built for Joseph Rathbone & Co, better known as the Coalbrookdale Co." Handsworth, "1780s Pumping Engine for the Coalbrook Dale Company," http://www.search.digitalhandsworth.org.uk/engine

[139] Hayman, "Shropshire Wrought-Iron Industry," 71.

the fall of 1785, Watt came to Albion Mills, located on the Surrey side of Blackfriar's Bridge in London, where his steam engines were to be installed. These were his advanced double-acting, rotative engines, proper for turning mills, and they were to be worked by his newly invented smoke-consuming furnaces (Figs. 10.29 and 10.30).[140]

Their industrial visits ended here, at Bradley. They began their return journey to London on this day, making geological observations as they traveled.

Day 22. August 7. This day was spent traveling, making frequent stops to measure elevations with the barometer.

Day 23. August 8. London, Bedford Square. This day began at the Star Inn in Oxford and ended in Cavendish's townhouse in London. The last barometer reading was made in Cavendish's library there. Four days after arriving home, Cavendish measured the height of his library above the hall of the Royal Society apartments in Somerset Place, and he compared the portable barometer he used on the journey with his stationary barometer at Bedford Square and also with a second portable barometer at his country house at Clapham Common. The traveling barometer examined, the journey was over.

10.7 Summary of Part II

During three consecutive years in the mid-1780s, Cavendish together with his associate Blagden made extensive journeys to different parts of Britain. In broad terms, the journeys took Cavendish on roads and to places he had not been to before, where he made geological observations and where he was shown mines and industrial plants in operation. Midway through his first journey, he saw Ironbridge cross the River Severn at Coalbrookdale, the first bridge to be made of cast iron. His father devoted years of conscientious administrative work to the building of Westminster Bridge, the second bridge across the River Thames after the centuries-old London Bridge. Westminster Bridge was going to be built of wood, but then it was decided to use stone, a more expensive but more durable material. In the iron and coal valleys of South Wales, the material foundation was beginning to be laid for new ways of construction and of living. If Cavendish sensed this when he saw Ironbridge, he kept it to himself, but he definitely would have realized that his world already was not his father's, and that it held new possibilities.

[140] Initially there were problems with the piston rod and the sun-and-planet gear of Watt's engine, but by early 1786 the repairs had been made. In 1789, a second engine was installed. In 1791, Albion Mills burned down. It bears on Cavendish's interest that in 1791 he together with Blagden, Banks, and the engineer John Smeaton were invited to inspect drawings of a steam engine and a waterwheel at Falcon Stairs, near Blackfriar's Bridge and the site of the former Albion Mills. Charles Blagden to Joseph Banks, 23 October 1785, Banks Correspondence, Royal Botanic Gardens, Kew 1:212. John Maitland to Joseph Banks, 19 December 1791, British Library, Add. Mss. 33979, p. 118.

Neither in the journals nor in any other writings from that time do we find indications of Cavendish's "peculiarities." A possible exception is the narrowness of his interests. If his journals were to be taken simply as scientific memoranda no different in kind from minutes of experiments in his laboratory, their narrow focus would be expected. Yet even if this were so, still it was his decision to confine his travels and journals within his narrow scientific interests, and this reveals an important side of his personality, which to his contemporaries appeared peculiar.

The Aristocrat. Cavendish made his journeys during a time when the British aristocracy was in ascendancy. This was also a time of industrialism. Aristocrats and industrial entrepreneurs alike benefited from the political temper of the period, which favored minimal government interference. Eventually the transfer of wealth to the rising middle class of industrial Britain would challenge the aristocratic order, but this prospect was remote, and it would not have troubled Cavendish. It was common in his day for aristocrats to participate in industrial undertakings, and they profited handsomely if their lands were found to hold mineral wealth. Cavendish inspected the installation of a steam engine at a lead mine in which the duke of Devonshire held part interest. Cavendish did not visit mines and ironworks out of monetary or class interest, but as an aristocrat he would have had no aversion either.[141]

The Natural Philosopher. Cavendish looked at mines, ironworks, and factories through the eyes of a natural philosopher, interested in their workings, in cause and effect. He showed no outward interest in the commercial side of industry or in the conditions of labor.

Strangers. As travelers do, he met new people along the way. They included innkeepers, villagers, farmers, miners, and ironworkers. They were given names if they were owners or engineers. The journals recorded information they provided, but nothing else about them.

Regularity and Routine. Travelers often become interested in something they did not foresee at the start, occasioned by the travel itself or a by a spontaneous impulse. Nothing in the journals suggests that Cavendish was such a traveler. We know that Blagden wished to see more of the Lake Country, but Cavendish was not interested. Before Cavendish set out on his journeys, he had a plan, which he did not significantly depart from. It called for observing the same few kinds of things at different places, noting any variations. He and Blagden took barometer and thermometer readings multiple times every day. This was the routine of the journey of 1785.

Wealth. On a whim, Cavendish took a 3-week journey because he wanted to. He could do it because he was wealthy and his time was free; he had no family or professional obligations to hold him back.

Physical World. Methods of extracting and purifying ore and other industrial processes offered Cavendish another avenue of the physical world to explore. In the machines, fires, and materials of metal production, he observed the interplay

[141] Cannon, *Aristocratic Century,* 6, 178–79.

of forces he was intimately familiar with from his studies in mechanics, heat, and chemistry.

Mathematical Mind. From industrial sites, he took away such measurements as were given him such as the sizes of hearths and the quantities of fuel and ore. They were part of the description, not the starting point of calculations of any length. It was otherwise with the readings of measuring instruments he brought with him– barometer, thermometer, and theodolite – which entered extensive calculations for elevations and latitudes.

Senses. Other than for measurements of elevations and occasional measurements of the angles strata made with the horizon and of the thickness of strata, his study of the earth was qualitative and relied on his sense of sight. His geological observations were discerning, comparable to his chemical observations in his laboratory.

Objectivity. His journals are impersonal, objective. They contain only technical and scientific descriptions and observations.

Accuracy. One of the main objects of his journeys was to measure heights of mountains with a barometer. Like others, he was interested in finding a method that was reliably accurate. In general, he and Blagden took pains always to describe what they saw on their journey accurately.

Knowledge. When Blagden told Cavendish about industry in South Wales, Cavendish was curious. He was curious to see it, to know.

Publication, Writing. He kept journals of his tours. It was a custom of the time, but it was also his practice to keep a written record of observations and explanations. Like most of his papers, he did not publish the journals.

Scientific Society. It was common for natural philosophers to take an interest in industry, and like Cavendish some of them made journeys to see industrial works and to make geological observations.

Way of Life. Cavendish's journals give us an idea of his view of the world. His industrial and geological tours were an extension of his interests, as we know them from his more sedentary activities. His regular reading of meteorological instruments on his journeys followed his practice of daily consulting instruments attached to his house or set out on his grounds on Clapham Common. When he returned from his journeys, he submitted his readings to calculations, deriving physical results. The rocks he collected on the journeys became material for chemical and physical analysis at home, and they probably ended up in museums in his townhouse. His observations of strata were incorporated in a comprehensive paper on the strata of the island, which he wrote after returning. He followed up his observations on industrial technology with requests for specimens from mines and smelting furnaces. His journeys were a stimulus to new directions in his research, our clearest evidence that he incorporated his journeys into his life of natural philosophy. The world beyond his laboratory was a larger laboratory, full of interest to this natural philosopher.